

**CORDILLERA REAL
GEOLOGICAL RESEARCH PROJECT**

**FIRST ANNUAL REPORT
(MARCH 1986 – MARCH 1987)**



British Geological Survey

**Keyworth
Nottinghamshire**

PATRI MATRIQUE



Miguel Pozo admires the serpentinite La Soledad, at 4000 m in the cordillera.

Antisana - Cosanga Traverse.

The great Andean adventure

The greatest moments of one's life,
You count them on one hand.
A high volcano was our start,
Then down through unknown land.
Battling Cosanga's raging stream:
A fortnight's journey spanned.

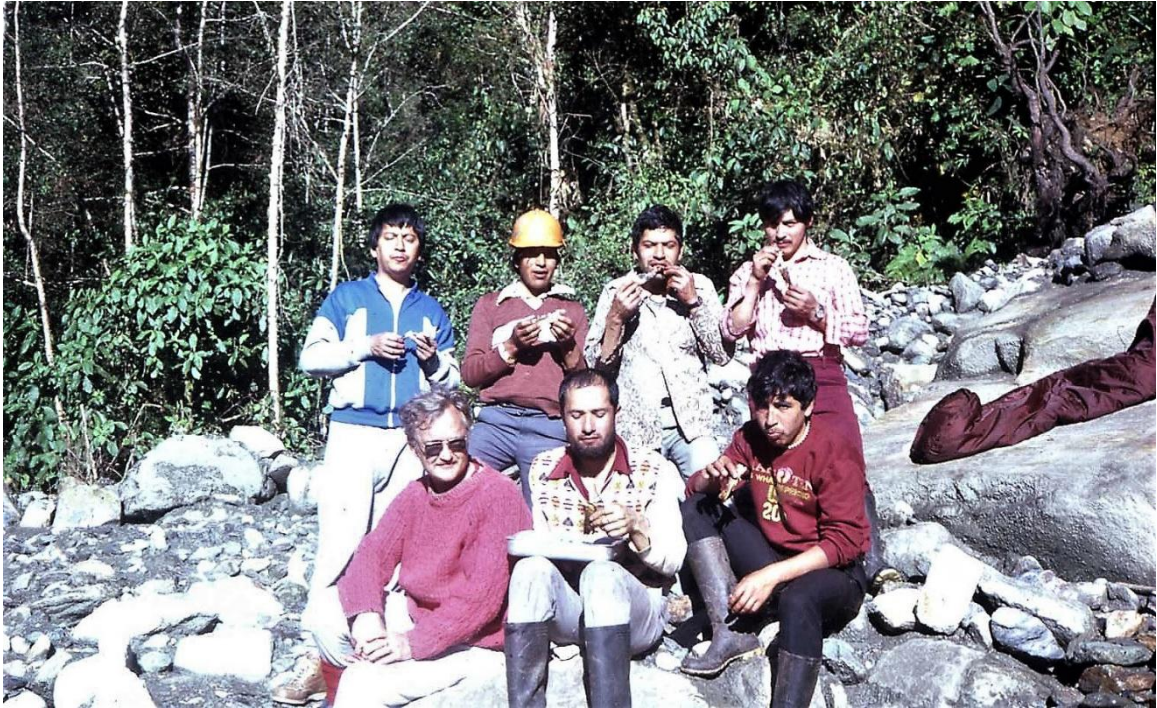
Frosty tents: the roof of the world,
Down to tropical climes.
Miguel, Manuel as company
Panting those airless climbs.
Laughing the river, to and fro:
Those were the greatest times.

Exciting were those rocks we found,
Where they should not have lain.
A great nappe complex filled the hills,
Due to a pushed terrane.
Serpentinites and skarnfields too
Were secrets to unchain.

The joys of finding so much new:
The scientific dream.
The exhilaration of the view,
The working as a team.
Then, past the point of no return,
Those struggles with the stream.

So those two weeks in Ecuador
Fulfilled my life I know.
All came together on that trip
As if in clockwork slow.
Sometimes I feel a sense of calm:
A satisfaction's glow.

Martin Litherland
Inca Treasure
Poems from the Andes of Ecuador



Having trout for breakfast at Río El Placer, a tributary of the Río Mulatos.
Gonzalo Viteri, "the one-handed man," in the center



Tungurahua volcano lavas over the metamorphic basement at the Río Pastaza

Overseas Development Administration,
Foreign and Commonwealth Office,
United Kingdom of Great Britain
and Northern Ireland

Ministerio de Energía y Minas,
República del Ecuador

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compiled by
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1. INTRODUCTION

1.1 Nature of this report

This is the first of a series of open file reports on the Cordillera Real Geological Research Project: a bilateral Technical Co-operation project between the Government of Ecuador (Instituto Ecuatoriano de Minería-INEMIN: Ministry of Energy and Mines) and the Government of the United Kingdom of Great Britain and Northern Ireland (Overseas Development Administration-ODA).

1.2 Background to the present project

ODA/BGS participation in the geological development of Ecuador began in 1969 with the arrival of Dr. J. B. Kennerley who started work on the geological mapping of the Loja Province and Llanganates area and for the next two years worked four months in the field each year in Ecuador. As a result of the success of this project, the Ecuadorian Government requested an expansion of geological aid and, in February 1972, Kennerley became leader of a residential team of five geoscientists, the British Geological Mission, all of whom worked with Ecuadorian counterparts. After the tragic death of Brian Kennerley in 1976, Dr. J. W. Baldock became team leader until the geological aid project came to an end in 1980.

These years of technical cooperation involved a programme of mineral investigation and systematic geological mapping over western Ecuador, culminating in the publication of a revised national geological map and outline of the geology of the country (Baldock, 1982).

The renewal of ODA/BGS participation in the Ecuadorian Geology stemmed from a visit by Dr. J. D. Bennett which coincided with the start of the government of Ing. León Febres Cordero with its policy of developing a viable minerals industry and providing greater incentives than before for national and foreign investment in mineral exploration and mining.

Bennett's project proposals (BGS Overseas Directorate Report 84/13), worked out in conjunction with DGGM (now INEMIN), were modified following comments and suggestions made by the Director of DGGM, Sr Horacio Rueda Jácome, and rewritten by Dr. B. G. N. Page in January 1985. The new project (Cordillera Real Geological Research Project) was the subject of Dr Jones' visit to Ecuador in 1985 (BGS Overseas Directorate Report MP/85/11/R); and the project began in March 1986, with the *convenio* being signed on May 15th of the same year. It could be said that the new Project represents an eastward extension of the regional studies undertaken by the previous British Mission.

1.3 The aims of the project

The subject of the Project is to study the metamorphic rocks of the Cordillera Real: the objectives are the elucidation of their nature, structure, relationships, genesis and mineralization in order to discover the patterns of metallogenesis and provide the scientific basis for estimating their mineral potential.

1.4 Personnel

For the first year of the Project the following officers were seconded to ODA from the British Geological Survey (BGS):

Dr. Martin Litherland (Team Leader)

Dr. John Arthur Aspden

The following officers of INEMIN were assigned to the Project as counterpart geologist:

Ing. Ramiro Bermúdez Almeida (Counterpart Project Leader)

Ing. Francisco Viteri Santamaría

1.5 Area of study

For the first year the study area was delimited as the metamorphic rocks of the Cordillera Real (Cordillera Oriental) of Ecuador, their westward extension within the Inter-Andean Depression, and their eastern extension to include the metamorphic, non-metamorphic and plutonic rocks of the Sub-Andean foothills.

1.6 Topography and drainage

Physiographically, Ecuador can be divided, from west to east, into the Costa, Sierra and Oriente. The Sierra comprises the Andean mountain chain which in Ecuador is only about 120 km wide and therefore constitutes the narrowest sector of the entire ranges along the western margin of South America. The region consists of two parallel ranges, the Cordillera Occidental and the Cordillera Real separated by the Inter-Andean Depression in central and northern Ecuador.

Elevations along the Cordillera Real watershed decrease southwards towards the Peruvian border. In the north the position of this watershed is controlled by the volcanos Cayambe (5790 m), Antisana (5704 m), Cotopaxi (5897 m), Tungurahua (5016 m), Altar (5319 m) and Sangay (5230 m) which provide a thick Quaternary volcanic cover to the metamorphic rocks over substantial areas. To the west these volcanos rise above the Inter-Andean Depression which reaches depths of around 2000 m. In the south, the Cordillera Real rarely penetrates the 3500 m contour. The highland watershed regions are extensively glaciated. The eastern slopes of the Cordillera Real are marked by a lowering of elevation to about 1000 m along a lateral distance of 30-50 km from the watershed. Streams and rivers are torrential and markedly incised. They join up along the Sub- Andean foothills to form the major rivers of the Oriente.

1.7 Climate and vegetation

There is a tremendous variation in climate and vegetation across the Cordillera Real. The Inter-Andean Depression is temperate with rainfall in the region of 600 mm per year (see Quito and Cuenca, Table No. 1), and with grassland vegetation. The western slope of the Cordillera Real is marked by wet paramo grasslands up to the snow-line (ca. 4500 m), country usually enshrouded in cloud. The tree line of the eastern slope montane forest is about 3700 m and the climate and vegetation become more tropical as one descends to the eastern lowlands. Rainfall is high over this eastern slope region; figures for Puyo and Tena, on the eastern lowlands show 3000-4000 mm per year (Table No. 1).

There is no dry season over the highlands of the eastern slope in the north, but local people claim that October to March are the "less-wet" months and this is borne out by the rainfall figures for Papallacta and Baños (Table No. 1). Rainfall patterns for the southern highlands (Loja, Vilcabamba) are more akin to those of the Inter-Andean Depression with the driest period from June to August.

1.8 Population

The population of Ecuador in 1984 was in the region of 9 million (Dir. Politico-Adm. Rep. Ecuador, Inst. Nac. Estat. y Censos, 1986) and is now probably nearer 10 million. About 40% of these are Indians and an equal number mestizos; the remainder being mainly white. Of the Indians the majority are Quechua-speaking descendants of the inhabitants of the Incan Empire and live mainly in the Sierra. A few other small groups exist in the eastern lowlands (Oriente). About 40% of the population live on the coast and 47% in the Sierra, mainly within the Inter-Andean Depression. The Inter-Andean highway links Tulcán in the north (ca. 32000 inhabitants) to Ibarra (53000), Quito (1000000), Ambato (100000), Riobamba (75000), Cuenca (53000) and Loja (71000). Over the Cordillera Real highlands population is sparse; sizable towns only exist along the main access routes (e.g. Baños-Puyo). In the east, the Sub-Andean highway links small towns, the largest of which are Puyo (11000), Zamora (7000), Macas (6000) and Tena (6000).

1.9 Access

The Cordillera Real is the most inaccessible region of Ecuador with respect to the combination of physical barriers and availability of tracks. This, coupled with its inclemental weather, has ensured that the region has remained largely unexplored topographically and geologically. From north to south access routes across the Cordillera are as follows:

- (a) Tulcán – Sibundoy (all-weather road) – La Bonita – Los Cofanes – (mule track).
- (b) Cangahua – Oyacachi – El Chaco (mule track)
- (c) Quito – Papallacta – Baeza (all-weather road)
- (d) Baños Puyo (all-weather road)
- (e) Guamate – Atillo (all-weather road) – San Vicente (mule track; road in construction) – Macas (all-weather road)

- (f) Cuenca – Paute – Amaluza (all-weather road) – Méndez (mule track)
- (g) Cuenca – Gualaceo – Limón (all-weather road)
- (h) Sigsig – Chigüinda (all-weather road) – Gualaquiza (mule track)
- (i) Nabón – La Paz (mule track) – Zamora (all-weather road)
- (j) Catamayo – Loja – Zamora (all-weather road)
- (k) Loja – Vilcabamba – Zumba (all-weather road)

These routes connect up with the Inter-Andean highway in the west (Tulcán-Quito-Riobamba-Cuenca), and the Sub-Andean road in the east (Lago Agrio-Baeza-Tena-Puyo and Macas-Limón-Zamora) which is broken only by the lack of key bridges between Puyo and Macas. This link, when completed will be vital to the development of the Oriente. Another road under construction is that from Guamote-Macas (see (e)). Projected roads include Tulcán-Los Cofanes (see (a)) and Salcedo-Tena.

The project is based in Quito. Driving time along the Inter-Andean highway to the north is: Ibarra (2 hrs 30 min) and Tulcán (5 hrs); to the south is: Riobamba (3 hrs 30 min), Cuenca (8 hrs) and Loja (17 hrs); and to the east is: Baeza (2 hrs 30 min), Tena (4 hrs) and Macas (16 hrs, via Cuenca). There are regular commercial flights from Quito to Cuenca, Loja and Macas.

1.10 Topographic maps and imagery

In terms of the Cordillera Real area, published surveyed maps of the Instituto Geográfico Militar on a scale of 1:50000 cover only the western slope region, the Inter-Andean Depression and a few sheets along the Sub-Andean foothills. The remainder of the area, i.e. the mountains, are covered by "census" maps drawn from air photographs but with gross distortions.

With the exception of a few "blank" areas, air photo coverage is available for the area on scales which vary from 1:40000 to 1:60000. LANDSAT satellite coverage is also available and mostly without cloud cover. There is also SAAR (radar) imagery. In all the imagery the expression of metamorphic lithologies and primary structures is poor or non-existent over the forested eastern terrain; only the narrow rocky glaciated watershed zone is of high quality for interpretation. Late brittle fault/joint patterns control the main lineaments.

In order to plot the Project results accurately, team members are at present preparing a 1:250000 base map of the area from LANDSAT imagery.

Table 1. Average monthly rainfall figures

	JAN.	FEBR.	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPT.	OCT.	NOV.	DIC.	TOTAL
Tulcán	59.67	82.87	90.22	120.26	62.96	56.74	44.30	49.57	63.44	99.97	132.88	102.44	965.32
Quito	50.20	72.20	69.20	71.30	48.40	30.30	22.90	29.80	54.10	52.20	55.40	64.20	620.20
Papallacta	63.27	107.67	108.01	108.65	159.06	180.08	193.05	107.81	109.31	95.48	84.13	82.98	1399.50
Cotopaxi	68.75	106.60	142.06	123.80	143.70	77.27	58.20	62.85	103.73	98.58	93.37	84.72	1163.63
Tena	147.75	167.66	269.77	343.40	325.54	380.56	246.95	268.62	287.57	310.34	343.31	212.20	3303.67
Baños	50.58	84.30	98.56	132.41	123.81	162.38	157.72	144.40	115.68	70.06	56.96	41.55	1238.41
Puyo	271.55	277.43	454.90	450.08	429.95	486.80	412.97	361.72	384.78	394.78	366.93	340.47	4632.36
Sucúa	41.06	90.86	127.41	125.12	130.92	171.81	115.40	114.67	123.15	99.80	84.12	36.91	1261.23
Paute	42.22	67.94	93.80	83.72	44.55	58.80	51.75	36.52	48.37	60.65	65.18	66.22	719.72
Cuenca	40.38	70.14	95.82	98.60	56.10	45.01	35.20	30.24	50.21	72.33	67.62	62.62	724.27
Loja	77.30	103.55	120.17	82.96	31.41	53.65	44.01	38.13	31.66	57.42	45.67	56.44	742.37
Zamora	90.71	97.43	147.95	124.00	104.76	146.25	126.08	114.83	95.68	85.10	115.30	125.47	1373.56
Vilcabamba	76.76	96.74	150.60	99.37	44.36	19.57	11.87	18.18	20.82	47.88	43.95	70.10	700.20

values millimetres

data source: Anuario Meteorológico (INAMHI). 1972-1981, calculated by Ing. Ramiro Bermúdez

for Quito: 1957-1984, Dir. Gen. Aviación Civil.

1.11 Geological framework

This, simply is of a metamorphic/plutonic nucleus, of essentially unknown age, forming the spine of the Cordillera Real and comprising schists, phyllites, quartzites, ortho- and paragneisses and granitoid plutons (Baldock 1982). To the west the metamorphic rocks are covered by late Mesozoic to Cenozoic sediments and lavas, and to the east they are thrust against variably deformed Paleozoic-Mesozoic sediments and volcanics of the eastern platform (Oriente) which represent a small part of the Phanerozoic cover over the Precambrian rocks of the great South American Platform (Almeida et al., 1981). The contact zone with the metamorphic belt along the Sub-Andean foothills is marked by elongate granitoid batholiths.

1.12 Review of previous work

1.12.1 Geology

Theodoro Wolf (1892) roughly delimited the metamorphic rocks of the Cordillera Real on the first geological map of Ecuador (scale 1:1000000) and presented a description under "Gneiss and schist formations" (p. 226- 235). Within the schists he noted chloritic, talcose, graphitic and amphibolitic varieties.

Walther Sauer (1950) produced the next geological map of Ecuador upon which the metamorphic rocks of the Cordillera Real are more accurately traced. In his synthesis (Sauer, 1965) of the geology of Ecuador, based largely on his own studies which began in 1935, he divided the basement of the Cordillera Real into metamorphic and semi-metamorphic units. The former (p. 24-48) he regards as Paleozoic, with possible Precambrian elements, and describes lithologies from wide-ranging traverse (Cayambe, Papallacta-Baeza, Antisana, Upper Río Mulatos, Llanganates, Baños-Puyo, Guamote-Macas, Azogues-Paute, Saraguro-Loja and Loja-Zumba). He also studied 'exotic' river float rocks. Sauer (1965 p. 48-50) confined the semi-metamorphic unit to: the Paleozoic rocks of the eastern platform; a transition zone between the metamorphic rocks and the Cretaceous sediments of the eastern platform; and various low-grade rock localities of the Cordillera Real and the El Oro metamorphic belt. The work of Tschopp (1945, 1948, 1953) over the eastern platform was incorporated into this synthesis.

Reconnaissance mapping over the Cordillera Real began with the studies of the Llanganates area (Kennerley, 1971) and Loja Province (Kennerley, 1973). The latter marked the beginning of the 1:100000 sheet reconnaissance mapping of the Cordillera Real by DGGM (later INEMIN). At the present, a number of these sheets are published (Ibarra, Otavalo, Baños, Riobamba, Alausí, Cañar, Azogues, Girón, Saraguro, Loja, Gonzanamá, Las Aradas and Zumba); other are in the press or in preparation (San Gabriel, Sangolquí, Píntag, Baeza, Chalupas, Archidona, San José de Poaló, Tena, Gualaquiza and Cumbaratza); whilst the remainder are unmapped or being mapped (Mariano Acosta, Reventador, Huamboya, Macas, Sucúa, Méndez, Sigüig, Zamora, Río Nangaritza and Jimbura).

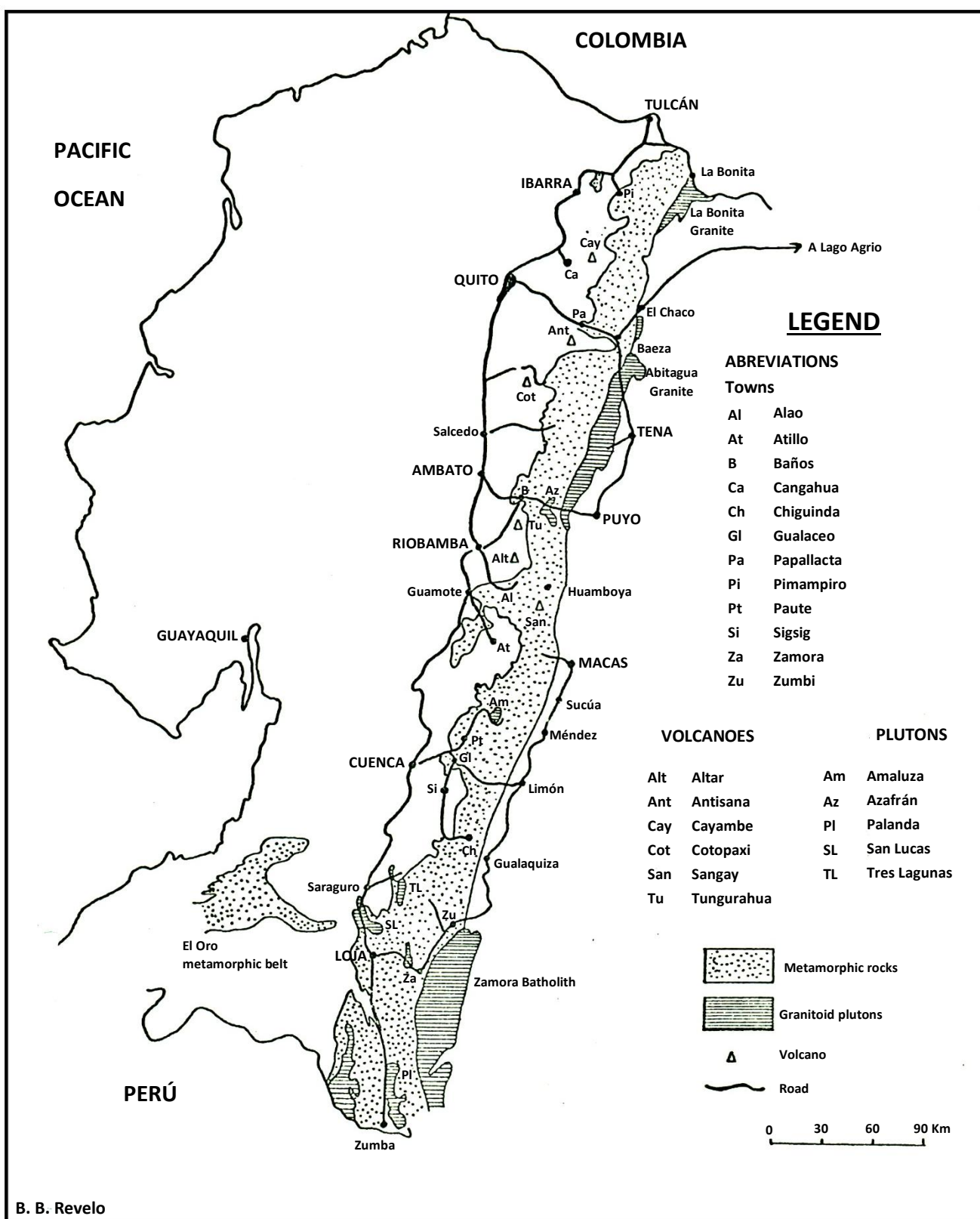


Figure 1. Main communications and geological setting (adapted from Baldock, 1982) of the Cordillera Real metamorphic belt; non-metamorphic units omitted.

On most of the 1:100000 sheets the metamorphic rocks are differentiated from the various cover sequences as a monochrome geological unit; with major igneous or meta-igneous bodies shown in different colours. In some instances, letter symbols are employed to identify lithological differentiation within the metamorphic rocks (gneiss, quartzite, schist, phyllites, etc.) along traversed sections, and these are referred to in the brief explanation printed on the map. However, away from road traverses, the metamorphic rocks have been little studied.

In recent years attempts have been made by individuals to study the metamorphic rocks using the limited road access (Papallacta-Baeza, Baños- Puyo, Cuenca-Limón and Loja-Zamora) to gain insight into the Cordillera Real as a whole. In this respect these studies anticipate the aims of the present project. Feininger (1975, 1982) concluded from his studies and available age dates that, with exception of the rocks close to the Peruvian and Colombian borders, the bulk of the metamorphic rocks were facies equivalent of the Cretaceous sequences of the eastern platform. Trouw (1976), after a vigorous petrological and structural study of the traverses, erected various formalised lithostratigraphic units and reached similar conclusions to that of Feininger with regard to age. Herbert's (1983) petrological studies of the same traverses and available age dates led him to suggest the northern higher-grade sector of the cordillera as Paleozoic in age and the lower grade rocks as possibly younger.

At the start of the Project the geologist with the most experience in Cordillera Real geology, and resident in Ecuador, was Ing. Pablo Duque of Quito Polytechnic. His researches have largely concerned the petrology and PT conditions of metamorphism of the Papallacta-Baeza and Baños-Puyo metamorphic sections.

1.12.2 Geochronology

Hall and Calle (1982) cite 16 K-Ar determinations, ranging from 50 to 90 Ma, for the metamorphic rocks of the Cordillera Real; though Table No. 2 only records 12 of these. Older dates are indicated by the few Rb-Sr studies (Table No. 2) but these are statistically invalid. There is also a reported K-Ar date of 417 Ma from the Agoyán gneisses.

With regard to the plutonic and meta-plutonic rocks an age of ± 180 Ma is recorded from the Palanda and Tres Lagunas plutons in the south and also from the undeformed Abitagua granite. The same age is indicated for the Azafrán meta-pluton by statistically invalid Rb-Sr results.

The remainder of the plutons, all of which cut the metamorphic rocks, fall into the 50 to 90 Ma age range with the exception of the younger Amaluza body.

The oldest date (743 Ma) from Ecuador is from an amphibolite of the El Oro belt, but a similar rock from the same location gave 196 Ma, an age found elsewhere in the El Oro sector but not in the Cordillera Real. Plutons in the El Oro belt give ages around 214, 110, 50 and 25 Ma.

Table 2. Radiometric ages from the Cordillera Real and El Oro Metamorphic Belt

(a) The Cordillera Real: Metamorphic basement

	Rock unit/rock type/setting/location	Source	Material analysed	Inferred age	Isotopic method/data
1	Central Belt, garnet gneiss, Baños-Puyo, Agoyán	Evernden (1961)		417	K-Ar
2	Central Belt, muscovite schist, Papallacta-Baeza	Kennerley (1980)	Muscovite	82 ± 3	K-Ar, 8.45%K
3	Western Belt, phyllites, Paute “Group”	Kennerley (1980)	Whole rock	92 ± 3	K-Ar, 0.415%K
			Whole rock	88 ± 2	K-Ar, 1.575%K
4	Central Belt, biotite gneiss, near Palanda	Kennerley (1980)	Biotite	72 ± 2	K-Ar, 8.01%K
5	Central Belt, biotite gneiss, near Zumba	Kennerley (1980)	Biotite	81 ± 3	K-Ar, 7.34%K
6	Central Belt, schist, Papallacta-Baeza, Baeza Pumping Station	Feininger and Silberman (1982)	Biotite	54 ± 2	K-Ar, 8.59%K
7	These authors report 6 K-Ar determinations of Baños-Puyo section between 54 and 79 Ma	Hall and Calle (1982)			K-Ar
8	Central Belt, biotite gneiss, Loja-Zamora	Baldock (1982)	Biotite	52 ± 2	K-Ar, 7.56%K
9	Western Belt, chlorite-muscovite schist, Río Paute, Cola de San Pablo	Herbert and Pichler (1983)	Muscovite	61 ± 2	K-Ar, 6.05%K
10	Central Belt, biotite-muscovite schist, Papallacta-Baeza, 4km E of Cuyuja	Herbert and Pichler (1983)	Muscovite	59 ± 2	K-Ar
			Biotite	59 ± 2	K-Ar
11	Central Belt, paragneiss, Baños-Puyo, 3km E of Agoyán tunnel	Herbert and Pichler (1983)	Muscovite	56.5 ± 2	K-Ar, 7.1%K
12	Central Belt, orthogneiss, Baños-Puyo, 2.5km W of tunnel under Pastaza bridge	Herbert and Pichler (1983)	Muscovite	60 ± 2	K-Ar, 8.76%K
13	Central Belt, gneiss, Baños-Puyo, Agoyán	Cordani (pers. comm.)		203 ± ?	Rb-Sr (one point)
14	Central Belt, Papallacta-Baeza	Darbyshire (pers. comm.)		308 ± 179	Rb-Sr (4-point) Statistically invalid
15	Central Belt, mainly gneiss, Baños-Puyo	Darbyshire (pers. comm.)		279 ± 98	Rb- Sr (11-point) Statistically invalid
16	?Central Belt, Amaluza road tunnel (mainly)	Darbyshire (pers. comm.)		115 ± 78	Rb- Sr (9-point) Statistically invalid

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(b) The Cordillera Real: Igneous and Meta-igneous rocks

	Rock unit/rock type/setting/location	Source	Material analysed	Inferred age	Isotopic method/data
17	Central Belt, Pimampiro pluton, metagranitoid	Evernden (1961)		72 ± ?	K-Ar
18	Abitagua Granite, near mouth of Río Topo, Baños-Puyo	Kennerley (1980)	Biotite	87 ± 7	K-Ar, 3.84%K
19	Magtayán pluton, hornblendite, near Atillo, probably cuts Western Belt	Kennerley (1980)	Hornblende	85 ± 3	K-Ar, 0.548%K
20	Amaluza pluton, granodiorite, cuts Western Belt	Kennerley (1980)	Biotite	36 ± 1	K-Ar, 6.9%K
			Hornblende	49 ± 2	K-Ar, 0.47%K
			Plagioclase	38 ± 1	K-Ar, 0.70%K
			K-feldspar	46 ± 1	K-Ar, 10.36%K
			Hornblende	39 ± 1	K-Ar, 0.47%K
21	Central Belt, Tres Lagunas metagranite, within Loja semi-pelitic basement	Kennerley (1980)	Biotite	78 ± 1	K-Ar, 6.2%K
			Plagioclase	173 ± 4	K-Ar, 0.43%K
22	Central Belt, San Lucas pluton, within Loja semi-pelitic basement	Kennerley (1980)	Biotite	78 ± 1	K-Ar, 5.5%K
			Plagioclase	173 ± 4	K-Ar, 0.65%K
23	Central Belt, San Lucas pluton, granodiorite, within Loja semi-pelitic basement	Kennerley (1980)	Biotite	62 ± 1	K-Ar, 0.63%K
			Plagioclase	63 ± 1	K-Ar, 7.80%K
24	Central Belt, Palanda pluton, granodiorite, within Loja semi-pelitic basement	Kennerley (1980)	K-feldspar	152 ± 4	K-Ar, 11.9%K
			Hornblende	173 ± 5	K-Ar, 0.68%K
			Biotite	180 ± 5	K-Ar, 6.26%K
25	Magtayán pluton, diorite, near Atillo, probably cuts Western Belt	Baldock (1982)	K-feldspar	54 ± 2	K-Ar, 11.39%K
			Hornblende	75 ± 3	K-Ar, 1.02%K
26	Abitagua Granite, mouth of Río Topo, Baños-Puyo	Herbert and Pichler (1983)	Biotite	178 ± 7	K-Ar, 4.93%K
27	Pheno-dacite, 4km SE of Baeza, could be regarded as phase of Abitagua Granite	Herbert and Pichler (1983)	Biotite	0.54	K-Ar, 6.10%K
28	Amaluza pluton, granodiorite, Río Paute, cuts Western Belt	Herbert and Pichler (1983)	Biotite	34 ± 1	K-Ar, 6.48%K
29	Central Belt, San Lucas pluton, granodiorite, within Loja semi-pelitic basement, between Saraguro and Loja	Herbert and Pichler (1983)	Biotite	50 ± 2	K-Ar, 5.59%K
30	Azafrán (meta) plutón, Central Belt, Baños-Puyo	Cordani (pers. comm.)		173 ± ?	Rb-Sr (one point)
31	Misahualí Member of Chapiza Fm, Jurassic volcanics, eastern platform	Espín (pers. comm.)	Whole rock	132 ± ?	K-Ar
32	Abitagua Granite	Halpern (pers. comm)		173 ± 5	Rb-Sr (3-point)
33	Azafrán (meta) pluton, Central Belt, Baños-Puyo	Halpern (pers. comm)	Hornblende	85 ± 3	K-Ar, 0.548%K

(c) The El Oro Metamorphic Belt and associated Igneous rocks

	Rock unit/rock type/setting/location	Source	Material analysed	Inferred age	Isotopic method/data
34	Amphibolite from Piedras Group	Kennerley (1980)	Hornblende	743 ± 14	K-Ar, 0.084%K
35	Tangula batholith, tonalite, possible extension of Perú coastal batholith	Kennerley (1980)	Plagioclase	110 ± 3	K-Ar, 0.23%K
			Hornblende	113 ± 3	K-Ar, 0.65%K
			Biotite	95 ± 1	K-Ar, 6.19%K
36	Tangula batholith, granodiorite	Kennerley (1980)	Biotite	49 ± 2	K-Ar, 4.84%K
			Hornblende	114 ± 30	K-Ar, 0.108%K
37	Amaluza granite, Peruvian border	Kennerley (1980)	Biotite	29 ± 0.5	K-Ar, 7.3%K
			Plagioclase	24.5 ± 0.8	K-Ar, 0.62%K
			K-feldspar	24.2 ± 0.8	K-Ar, 10.4%K
38	El Tingo “granodiorite”	Kennerley (1980)	Hornblende	47 ± 2	K-Ar, 0.64%K
			Biotite	50 ± 3	K-Ar, 1.21%K
39	Amphibolite from Piedras Group	Feininger and Silberman (1982)	Hornblende	196 ± 8	K-Ar, 0.238%K
40	Pelitic gneiss, Tahuín Group, South of Ráspas Fm.	Feininger and Silberman (1982)	Biotite	210 ± 8	K-Ar, 8.51%K
41	Pelitic schist, Ráspas Formation	Feininger and Silberman (1982)	Phengite	132 ± 5	K-Ar, 8.48%K
42	Marcabéí pluton, quartz diorite within low-grade Tahuín Group, south of Ráspas	Feininger and Silberman (1982)	Biotite	214 ± 6	K-Ar, 7.78%K
43	Amphibolite, in gneisses north of Ráspas	Feininger and Silberman (1982)	Hornblende	74 ± 1	K-Ar, 0.444%K

1.12.3 Analysis of previous geological work

Recent summaries of the geology of the Cordillera Real (Baldock 1982, 1985) illustrate the confusion produced by theories based on inadequate or insufficient data: lithological, structural and geochronological, thus making the Cordillera Real the last major challenge in terms of the geological understanding of Ecuador. Reading between the lines of Baldock's summary, there are clearly no adequate controls on litho-stratigraphy, structural history and geochronology to permit any serious attempt at a synthesis of the geological history and its place in the context of the Ecuadorian Andes.

Individual attempts to analyse the rock association of phyllites, schists, quartzites and ortho- and paragneises of the Cordillera Real have foundered due to lack of lithological and structural controls from one traverse to another along wide traverse spacings. Clearly, there are no obvious 'marker' bands or sequences nor lithological expressions on imagery of compositional types. Understanding has not been helped by the premature formalisation of lithostratigraphic units in the form of local Groups and Formations where neither age nor geographic limits nor field relationships are known. Such terms (e.g. Llanganates, Zamora and Ambuquí 'Groups') have no scientific significance and their common usage only helps to detract from the eventual understanding of the complex. In this respect, Herbert (1983) should be congratulated on his rock subdivision (I, IIa, IIb, III) according to age and metamorphic grade since these are informal and can be freely amended.

Clearly the rocks of the Cordillera Real cannot be assessed until their age is established and this cannot be achieved until methods other than K-Ar are utilised, since the K-Ar 'clock' is liable to be reset by younger tectono-metamorphic events. However, most previous workers agree that the rocks close to the Colombian and Peruvian borders are Palaeozoic in age with possible Precambrian remnants; this based on data from the extension of the Cordillera Real rocks in those neighbouring countries. In Perú the equivalent belt is unconformably overlain by Triassic (Zaña Group) sediments and perhaps by Devonian (Ñaupe Formation) quartzites (Cobbing et al., 1981). In Colombia, the Cordillera Real of Ecuador bifurcates to form the Cordilleras Central and Oriental, both of which contain Palaeozoic elements and the latter Precambrian (Feininger 1980; Kroonenberg 1982).

The bulk of the metamorphic rocks of the Cordillera Real away from the national boundaries have been assigned either a Palaeozoic or Cretaceous age depending upon the lithological comparisons, grade of metamorphism and K-Ar ages selected. The lower-grade "semi-metamorphic" rock on the flanks of the cordillera have especially attracted a younger age. In the west, Bristow (1973) reported a transition from the fossiliferous Yunguilla Formation (Upper Cretaceous) into rocks of the "semi-metamorphic" Paute "Group"; whilst in the east Feininger (1975) reports the passage of Cretaceous Hollín and Napo Formations of the eastern platform into low-grade "semi-metamorphic rocks" of the Sub-Andean belt, also referred to as the Margajitas "Group" (Baldock 1982). However, even if these observations are correct, no one has yet been able to demonstrate the corresponding transition into the higher-grade core of the cordillera, thus establishing a Cretaceous metamorphic belt. In this respect it is pertinent to note the tendency for the Rb-Sr studies, albeit statistically invalid, to indicate pre-Cretaceous dates for these rocks.

One puzzling feature of the previous work involves the "change" along the strike of the Cordillera Real between latitudes 2° and 3° S. Trouw (1976) regards those rocks to the south as a Palaeozoic flysch sequence of Abukuma-type metamorphism and those to the north as a Mesozoic sequence with a more varied composition including metavolcanic units metamorphosed under Barrovian greenschist facies conditions. Feininger (1982) follows Trouw in age interpretation but cites amphibolite facies conditions for the southern series. Herbert (1983), however, suggests that the southern sequence is younger and indicates a lower metamorphic grade for these rocks.

The plutonic history of the Cordillera Real is also little known or understood, and it is clear from the latest 1:1000000 National Geological map (Baldock, 1982) that plutonic rocks have only been depicted along the lines of vehicle access, indicating the possibility that plutonic chains exist across the unexplored areas. Little is known of the composition, form and age of the major plutons nor the relationship of the tectonic structures in the metagranites (orthogneisses) with those of their schist/paragneiss envelopes.

No assessment of the geological history of the Cordillera Real can be made without taking into account the metamorphic rocks of the El Oro Province which possess an E-W strike markedly oblique to the NNW trend of the Cordillera Real. The contact between the two belts is covered by younger sequences north of Catamayo. The rocks of El Oro (Feininger 1980) contain a central unit of dominant greenschists and amphibolite (Piedras Group) believed to be Precambrian in age based on one K-Ar determination (Table 2 No. 34). This envelope a Cretaceous ophiolite and blueschist complex (Raspas Formation) and are bounded to the north and south by low to high grade semi-pelitic rocks (Tahuín Group) believed to be of Devonian age. K-Ar dates from the Tahuín Group and enclosed deformed plutons suggest a late-Triassic event (Table 2).

1.12.4 The significance of the Cordillera Real in the Ecuadorian Andean setting

Ecuador is situated on the change from the Central Andes (Chile-Perú) to the Northern Andes (Colombia-Venezuela) (Gansser, 1973). This change begins at the Amotape structure (Huancabamba deflection), which in Ecuador is represented by the E-W trending rocks of the El Oro metamorphic belt. It also coincides with the most pronounced aberrant structures which run due west into the Pacific Carnegie ridge and the Galapagos Island (Gansser, 1973). Whilst the E-W trends of the Amotape cross structure are truncated in the Catamayo area by the Andean trend of the Cordillera Real of Ecuador, this same cordillera shows a trend deflected from NNE (in Ecuador) to NNW (in Perú) about an E-W axis.

The Huancabamba deflection not only marks abrupt local changes, or regional swings, of strike; it also represents the northward change from autochthonous to allochthonous Andes, in terms of Phanerozoic history. Thus, in Perú-Bolivia the Palaeozoic fold belt of the Eastern Cordillera was semipelitic and ensialic, bounded to the west by the Arequipa Massif of Precambrian basement, and deformed at around 330 Ma (Laubacher and Megard, 1985). These rocks were then overlain by Carboniferous and Permian continental sedimentary and volcanic rocks, deformed and intruded by late Permian to Triassic magmas. In contrast, in Colombia, the Palaeozoic rocks of the Central Cordillera are interpreted as a continental margin subduction/collision sequence with identified forearc/trench and back-arc zones (McCourt et al., 1984). These are cut by the 211 Ma Santa Bárbara batholith. Thus, the identification and study of Palaeozoic rocks in the Cordillera Real of Ecuador must carry great significance in the understanding of the nature of this fundamental northward Palaeozoic change from intracratonic to continental margin activity.

A similar change from the Central to Northern Andes occurred in the Mesozoic-Cenozoic (Andean Orogeny) eras. In Bolivia and Perú, continental margin subduction under the Arequipa massif produced the western Perú trough and the Coastal batholith, the northern limits of which can be identified as the continental volcanic Celica Formation and the Tangua batholith of the El Oro Province of Ecuador (Baldock, 1982). Further north, however, the coastal terrain and western cordillera of Ecuador and Colombia are allochthonous (exotic) and were accreted onto the South-American continent during the Mesozoic and Cenozoic. McCourt et al. (1984) record early Cretaceous and late Cretaceous phases of accretion against the Palaeozoic continental margin, the latter corresponding to the Ecuadorian accretion of the Macuchi are, Cayo and Piñón Formations (Lebrat et al., 1986). It is possible that this latter event could have reset the K-Ar clock over the Cordillera Real, but where is the evidence for the Early Cretaceous accretion? Is it found in the 132 Ma Raspas blueschists and ophiolite sequence of El Oro (Feininger 1980)? If so then it should also feature in the Cordillera Real sequence to the north.

1.13 Mining and mineral history

1.13.1 Gold and silver

In the early days of the occupation of the Pacific Coast of South America by the Spanish conquistadores, the Kingdom of Quito, which is now part of Ecuador, was famed for its richness in gold. History records that the Inca king, Atahualpa, treacherously imprisoned by the Spanish, offered to ransom himself by filling a council chamber with gold, which done, his captors afterwards put him to death.

It seems certain that the gold won by the Incas was obtained largely from placers (Holloway, 1932) many of which were found in the rivers draining eastward from the Cordillera Real.

During the 16th century the Spanish rapidly exploited the gold and silver deposits of Ecuador, which, with the exception of Zaruma (in the El Oro metamorphic belt) were located along the Cordillera Real or in the Sub-Andean foothills to the east (Febres Cordero et al., 1986; Navarro, 1986). After exploiting the alluvial gold of the Río Santa Bárbara (near Gualaceo), mining centres were established at Sevilla de Oro (near Macas) and Logroño (both alluvial gold) and Zamora, where primary gold was processed from many mines including Nambija. Later cities such as Baeza, Archidona, Avila (all working alluvial gold) were founded, along with Méndez, Macas, Santiago de Las Montañas, Jaén, Valladolid and many others, the sites of some of which cannot now be traced. Thus, were established 20 Spanish settlements in the Amazon basin during the 16th and 17th centuries compared to only 6 in the Sierra and 3 on the coast.

The gold mining virtually ceased after the 17th century due to maltreatments of Indians, disease and economic factors, and Ecuador changed from a mining to an agricultural-based economy (Febres Cordero et al., 1986).

At present, gold mining over the Cordillera Real and the Sub-Andean belt is concentrated in the Nambija area, although alluvial deposits are worked elsewhere on a small scale along rivers draining east from the Cordillera Real. From north to south these rivers are part of the following systems: Aguarico-Quijos-Cofanes; Napo-Mulatos; Pastaza-Palora; Upano-Paute; and Zamora-Nangaritza (Holloway, 1932; Mapa de Potencial Aurífero Aluvial, DGGM, 1983).

In the Río Nangaritza values of 11.65 gr/m and 5.43 gr/m of alluvial gold have been reported (Salazar, 1986), whilst in the Río Villano 19.5 gr/m was recorded. The alluvial gold diminishes eastward and below the 300 m contour the grains are less than 1 mm in size. The natives wash gold in the summer months along the Anzu, Jatunyacu and Napo rivers (Salazar 1986).

Placer gold terraces are known to exist near Tena, near the confluence of the Anzu and Mulatos (Jatunyacu). They are less than 2 m thick with a 1 m lower level of gold gravels with values of 0.3 - 0.8 gr/m. In the Río Mulatos the terraces reach 4 m in thickness with values of 0.4 gr/m (Salazar 1986). Colluvial gold has been exploited in Collay.

Thus, alluvial gold is derived from all latitudes of the Cordillera Real and not just from the southern sector where primary gold has been located and mined. Wolf (1892) noted the paradox between the paucity of reports of primary vein gold and the abundant placers and suggested that the gold may be disseminated in the metamorphic rocks. However, it must be noted that the primary gold locations of the south of the cordillera coincide with the sector of more subdued relief and relatively easier access.

The Nambija area is the site of a recent 'gold rush'. The metal is concentrated in skarn rocks produced by granitoid intrusions (Zamora batholith) into calcareous sediments, both of unknown age. The gold is worked by primitive methods. Values as high as 200-250 gr/tn have been reported with an average of 14-15 gr/tn, and there is an annual production rate in the region of 2 tonnes and reserves of 300 to 900 tonnes (Febres Cordero et al., 1986). Smaller mines are presently being worked in the vicinity of Nambija.

1.13.2 Other metals

Metallic mineral occurrences have been reported along the Cordillera Real (Goossens, 1969; Paladines, 1980); the bulk of which are from small polymetallic (Cu, Pb, Zn, Ag, Au, Sb) hydrothermal veins. These are said to be particularly prominent in the Llanganates and Sigisig areas (Paladines, 1980), and there is also a Pb-Zn-Ag prospect at Cumbaratza near Nambija. The Llanganates area is considered by many to have a considerable metalliferous potential partly based on old legends and maps (e.g. Spruce, 1861), but the area has not been subjected to serious geological and mineral explorations.

The Sigisig prospect takes the form of a lens, within gneiss and schist, containing magnetite, sphalerite, chalcopyrite, pyrrhotite, native bismuth and bismuthinite. It was previously worked for gold (Paladines, 1980). Most of the primary gold mines worked by the Spanish in the south of the area were probably also of polymetallic type.

Paladines (1980) also reports cassiterite and scheelite related to the ?greisenisation of granitoid stocks in the Saraguro and Sigisig areas.

The mineral maps of Paladines and Goossens also indicate small deposits of Mo, Fe, Li and Mn minerals over the Cordillera Real.

1.13.3 Non-metallic and precious stones

Paladines (1980) reports a number of occurrences of non-metallic minerals in the metamorphic rocks of the Cordillera Real. These include: anthracite, graphite, gypsum, mica, oil shale, pyrophyllite/talc and travertine. None of these deposits have been exploited on a large scale.

There are unconfirmed reports of rubies in the extreme south of the Cordillera Real near Zumba.

1.13.4 Mineral potential in relation to geological history

Using the available age dates, Van Thournout (1986) has suggested a Jurassic plutonic event to produce the great batholiths (La Bonita, Abitagua, Zamora) of the Cordillera Real and Sub-Andean belt, along with the Jurassic Chapiza volcanic Formation of the eastern platform. Whilst the undated Zamora batholith gave rise to the Nambija gold skarns and the Cumbaratza Pb-Zn-Ag prospect, but there is no information to tie the alluvial gold further north to the remaining batholiths. In Colombia, the Jurassic batholith chain continues along the same line and is marked by copper porphyry prospects (Sillitoe et al., 1982).

It has been suggested (Baldock, 1982) that southern Ecuador may represent the northernmost part of the Central Andes polymetallic belt developed in Chile, Bolivia and Perú. This evolved in the Jurassic/early Cretaceous when volcanic arcs of an incipient, rather basic, partly tholeiitic, calc-alkaline nature were associated with metal deposits with a small atomic number (Fe, Ni, Mn, V, Cr, Co). In contrast, in the final stages of evolution of the belt in the middle-late Cenozoic when the continental cover was thick and calc-alkaline magmatism had reached the granitic extreme, high atomic number metal deposits (Sn, Bi, Sb, W) were developed with high Mo/Cu ratio porphyry-type deposits (Frutos, 1982).

1.14 Methodology of the project, first year

During the first year's work, of which this report is a summary, the most pressing need was to get to know the geology of the Project area. This was accomplished by means of a series of geotraverses across the strike of the belt using, for the most part, the available access, road and mule track, indicated in section 1.9 and on Figure 1. Two less accessible traverses were also attempted: that from Licto to Huamboya (Figure 1) was abandoned 2 km east of El Placer due to bad weather and swollen rivers; that from Salcedo to Tena, following the course of the Río Mulatos, was accomplished, despite the difficulties presented. Additional work was carried out at Nambija/Guaysimi and Peltetec-Huarguallá.

The Papallacta-Baeza traverse was undertaken as a training exercise to familiarize members of the team with the metamorphic terrain and to standardise a common structural-lithological terminology; Ing. Pablo Duque and Dr. Arturo Egüez, both of Quito Polytechnic, helped with the familiarisation. The remaining geotraverses were divided between two Project groups: Litherland and Bermúdez undertaking those north of latitude 2° 30' S, and, Aspdén and Viteri those to the south. This partition of the Cordillera Real, though restricting the experience of each group in terms of the regional geology, was designed to facilitate correlation between adjacent geotraverses, considered to be of more vital import.

Each geotraverse was designed to obtain the maximum geological data over the metamorphic rocks and Sub-Andean belt as follows:

- (a) Lithological and structural studies of outcrop .
- (b) Studies of river and stream float and talus blocks; the former yields 'exotic' material not found in outcrop along the traverse route.
- (c) Collection of petrological samples for microscopic thin sections studies.
- (d) Collection of mineralised samples for microscopic studies and laboratory chemical analysis.
- (e) Collection of samples suitable for K-Ar geochronological isotope analysis.
- (f) Collection of fluvial samples for geochemical analysis. These were sieved in the field down to 80 mesh fraction size.
- (g) Collection of panned heavy mineral samples for qualitative gold analysis and mineral identification.

After each geotraverse the following were presented to INEMIN (in Spanish).

- (a) Field report (without microscopic studies).
- (b) Geological/mineral map (1:50000 scale).
- (c) Geochemical sample location map (1:50000).
- (d) Petrological/geochronological sample location map (1:50000).

1.15 Report presentation

This report is produced in Spanish and English. In order to save time, the field reports and maps (geological and geochemical only) are presented as appendices, without translation in the English version, and without the addition of any later microscopic or geochemical data.

1.16 Acknowledgements

During the first year, financial and administrative support were provided by INEMIN through the Gerente General, Sr. Horacio Rueda J.; ODA (Latin American Desk) and the British Embassy in Quito through Mr. R. Norton. Scientific support was provided by INEMIN through the Gerente Técnico, Ing. E. Salazar, and the Chillogallo laboratories; and by BGS through Dr. C. R. Jones.

We also appreciate the efforts of INEMIN drivers and the locally-recruited campesinos, without whom the mule-and foot traverses could not have been accomplished.

2. GEOLOGY

2.1 Introduction

This section is a summary of the geology of the geotraverses based on the field reports, presented as Appendices, and accompanying field maps. New data, in the form of rock analyses and microscopic studies is also included, but owing to the present difficulties in obtaining microscopic thin sections the petrology is largely based on field observations and detailed petrology will have to await the 1988 report.

At this early stage of the study, instead of formally erecting meaningless lithostratigraphic units, the metamorphic rocks of the Cordillera Real and environs are referred to as the “Metamorphic Complex”. However, to make this description more meaningful, and since some fundamental comparison can be made from one geotraverse to another, this complex is divided into three belts as follows (Figure 2):

- (a) The Western belt: limited to the east by the Baños front.
- (b) The Central belt: limited to the west by the Baños front and to the east by the Sub-Andean front.
- (c) The Eastern belt: limited to the west by the Sub-Andean front.

2.2 The Western Belt

2.2.1 Introduction

This belt was first recognised in the Peltetec area where it consists of serpentinites at Peltetec and the associated Peltetec subduction complex. It is now also considered to include the previous Paute Group and parts of the previous Ambuquí, Llanganates and Zamora Groups of Baldock (1982).

Four lithological (and probably tectonic) divisions can be recognised across the Peltetec section; from west to east these are:

- (a) The Guamote quartzite division.
- (b) The Cebadas black phyllite division.
- (c) The Peltetec subduction complex.
- (d) The Alao greenstone and metasedimentary division.

Metamorphism is within the low-grade facies of Winkler (1976) but increases slightly to the east towards the Baños front.

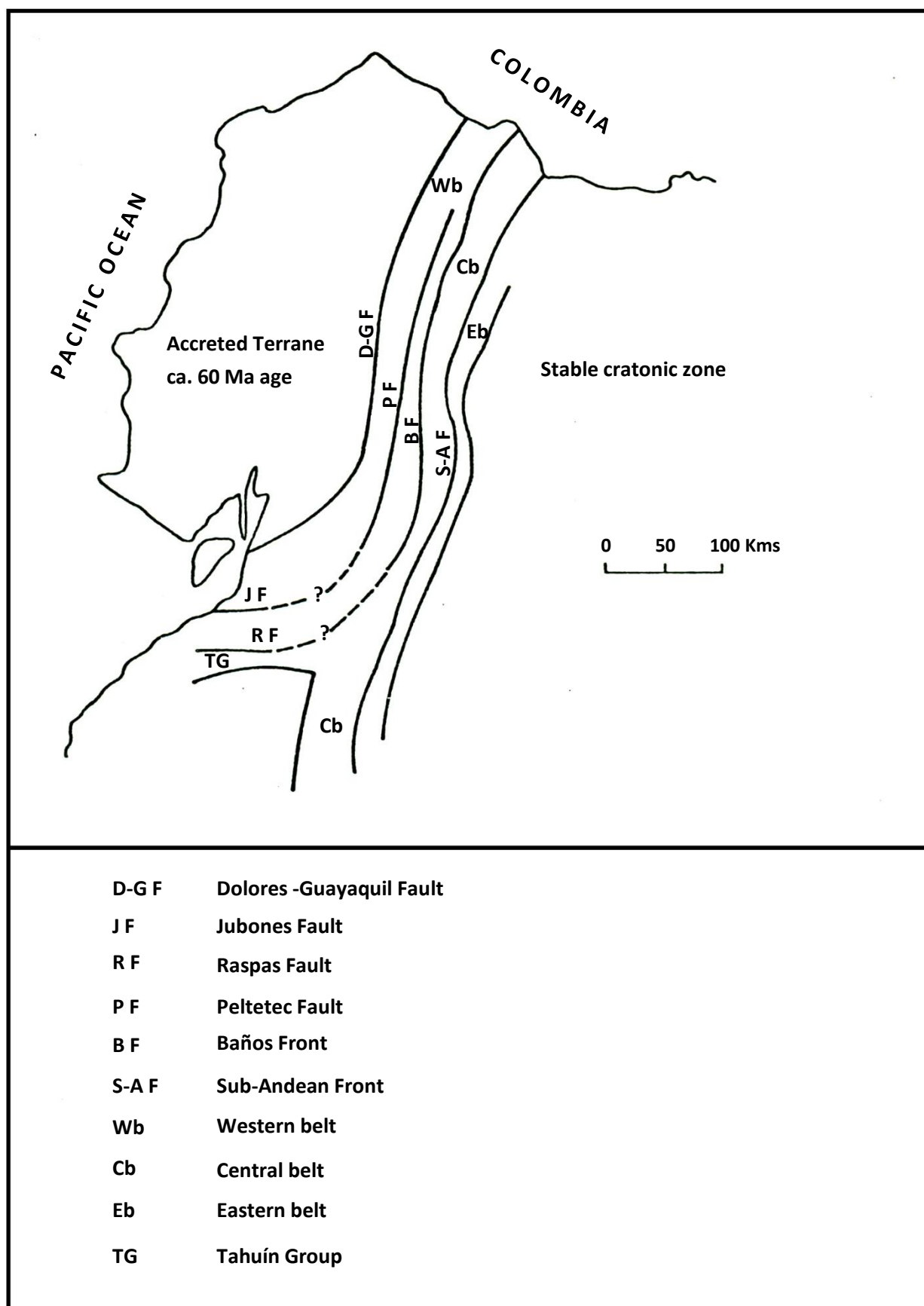


Figure 2. Major geotectonic units of Ecuador showing the new provisional lithological belts/tectonic divisions of the Cordillera Real and their possible SW extension into the El Oro Province; Cenozoic cover not shown.

2.2.2 The Guamote quartzite division

This belt, at least 8 km wide, represents the westerly limit of the Metamorphic Complex within the Inter-Andean Depression. Outcrops comprise massive reddish and pale, fine-to-medium grained, orthoquartzite. These are intercalated with red, purple, pale green, grey and black phyllites. Most outcrops show an ENE-trending (oblique to the Andean trend) subvertical crenulation cleavage (S₂) associated with open folds which affect a subhorizontal bedding (S₀)/S₁ layering containing D₁ (first deformation) tight-to-isoclinal folds.

2.2.3 The Cebadas black phyllite division

This comprises black graphitic phyllites intercalated with grey and pale quartzites within a belt, ca. 5 km wide. From the information it appears that this division has the same tectonic history as the Guamote division.

2.2.4 The Peltetec subduction complex

The most complete section so far located across the Peltetec subduction complex is exposed along a new irrigation canal along the northern slope of the Huargualla Valley. Here the Cebadas division is followed eastward by:

- (a) Ca. 10 m of sheared granite with bluish quartz and smoky feldspar, similar to the blue quartz metagranites of the western margin of the Central belt close to the Baños front. Outcrops indicate a tectonic slice structurally underlying the serpentinite.
- (b) Ca. 5 m tectonic slice of black phyllite and quartzite.
- (c) Ca. 15 m of E-dipping serpentinite becoming more asbestos rich towards the base.
- (d) Ca. 5 m of metagabbro and metalava.
- (e) Ca. 10 m of serpentinite.
- (f) Ca. 300 m exposure gap.
- (g) Ca. 100 m of black phyllite, quartzite and greywacke. From here the rocks are essentially sub-vertical in altitude.
- (h) Ca. 100 m of pale spillitic metalava.
- (i) Ca. 100 m of purplish silicified fine-grained metasediments with carbonaceous chert (lyddite) nodules. Purplish sediments contain 6-7% total iron (see 126B and D, Appendix 1). These are intercalated with pale green metatuffs (?metalavas) with asbestos veins.
- (j) Ca. 50 m of spillitic lavas.
- (k) Ca. 300 m black phyllites, quartzites and greywackes with 1 m graphite-rich bands.
- (l) Ca. 200 m of spillitic lavas and mauve shales with calcite veins well-developed in the lavas. One black limestone block noted.

Many of the lithological contacts can be identified as tectonic slices. The second cleavage (S2) is also steep, with an Andean trend. In the same subduction complex of the Peltetec section to the north there are also loose blocks of serpentinite breccia, and pillow lavas with pale cores and black chilled margins.

This complex can be traced southwards to the Guamote-Atillo road west of Río Cebadas, where, east of the Cebadas division there are:

- (a) Black and green cherts (ca. 200 m).
- (b) Metagranite with megacrystic smoky feldspar (ca. 50 m).
- (c) Black silicified fine-grained sediments and greywackes (ca. 1 km).

2.2.5 The Alao greenstone and metasedimentary division

This extends eastwards from the Peltetec subduction complex for a distance of ca. 15 km to the Baños front. Rocks are dominated by massive-to-schistose greenstones with minor green and pale cherts and black phyllites. Graded greywackes are prominent in the west. Ferruginous black sediments (24% total Fe) have been noted (No. 86, Appendix 1). A steep Andean-trending second cleavage is prominent over this sector.

2.2.6 Northward extension of the lithological division of the Western belt

To the north, the Alao division can be identified across the section from Patate to Baños. The rocks are identical: greenstones, greenschists, black phyllites and minor quartzites, cherty in places, and thin black marbles. Slightly further north, at Río Blanco de Patate, there are gabbros and greenstones. It is possible that the former could represent oceanic material along the projected line of the Peltetec subduction complex. Structural observations along the Patate-Baños section indicate major vertical Andean-trending D2 folds and cleavage (S2) refolded in the west (by D3) into an S2 fiat belt; the D2 fold pattern suggests an original sub-horizontal So/S1 regime.

Much further north, near Ambuquí, there is a basement 'window' within the Inter-Andean Depressions. Structural trends vary from N to NNW and there is a clear division between black phyllites, quartzites and black cherts in the west, from greenstones to the east. The contact is tectonic, along S2, and, though no ophiolites are present, the chert fraction increases towards it. Thus, the black rocks are provisionally correlated with the Cebadas division and the greenstones with the Alao division. Tectonically the rocks show upright open D3 folds affecting an S2 subhorizontal regime.

2.2.7 Southward extension of the lithological division of the Western Belt

On the watershed region of the Guamote-Macas traverse the Alao greenstone division was identified on both sides of a major shear zone prominent on imagery. Green and pale cherts and black phyllites are subordinate lithologies. From this location the Alao division can be reasonably traced further south into the former type area of the Paute "Group", crossed by the Paute-Méndez and Gualaceo-Limón geotraverses. The metavolcanic fraction (the old San Francisco "Formation", Bristow et al., 1980) comprises greenstones of probable andesitic origin with minor green and black phyllites and impure quartzite horizons. In the best-preserved section, agglomerates, lavas and tuffs can be seen as the volcanic components and pillow structures have been tentatively identified. The other unit, the "schists" of El Pan, to the east of the greenstones, is predominantly of a semi-pelitic sequences of black phyllites, green feldspathic (?volcanic) phyllites, quartzites and minor black marbles. The dominant tectonic structure in these rocks is a steeply- dipping Andean-trending first cleavage (S1).

2.2.8 Intrusions

There is a NNW-trending chain of post-tectonic, calc-alkaline intrusions extending from Licto-Pungalá, along the Cebadas Valley (abundant float), to the Atillo region. Granodiorite dominates with lesser diorite and hornblendite. K-Ar dates give 75-85 Ma, see Nos. 24 and 25 (Table 2). However, the apparent extension of this belt to the SSE encompasses the Amaluza Pluton (granodiorite-tonalite) which gives K-Ar dates from 34 to 49 Ma (see Nos. 26 and 27, Table 2).

Syntectonic concordant or semi-concordant felsite or microfeldspathic dykes have been noted at a few localities. Near Guamote these are deformed by the local S2 cleavage.

2.3 The Baños Front

This line marks the division between the Western and Central belts of the Metamorphic Complex. It was first proposed to indicate a hiatus about 1 km east of Baños where low grade rocks, now attributed to the Alao greenstone and metasedimentary division of the Western belt, are juxtaposed against garnet schists and gneisses, with minor amphibolites, to the east; the change being marked by the appearance of primary blue quartz in the metamorphic rocks. This hiatus was interpreted as a change from a younger Western belt sequence to an older Central belt sequence, but his hypothesis awaits testing by geochronological, palaeontological and structural studies. With reference to the latter, whilst detailed sequential structural studies were carried out across the Baños section it was assumed, at that early stage, that S1, S2 etc. were correlatives across the hiatus. This now requires field checking.

North of Baños, Map 1 shows the Baños front traced under the Cenozoic lava cover along the western edge of the Cordillera Real. To the east all the basement rocks are dominated by gneisses and schists with garnet and chloritoid. Thus, the line is drawn to separate the Ambuquí basement (Western belt) from the schists of Pimampiro where the greenschists are of slightly higher grade.

To the south of Baños, between Alao and Huamboya, the front can be traced dividing the Alao greenstones from blue quartz granites and schists of the Central belt. Further south, the tectonic line can be seen on imagery to bifurcate; the eastern lineament is taken as the Baños front since the western is enclosed by Alao greenstones. The front is continued south, then SW, to coincide with a mylonitic tectonic/lithological hiatus noted in the field across which there is little or no change in metamorphic grade.

2.4 The Central Belt

2.4.1 Introduction

The informal erection of this belt, which geographically represents the Cordillera Real 'proper' and also the logical link-zone of the Colombian and Peruvian Palaeozoic belts, is facilitated in the north by its higher grade of metamorphism and complex meta-plutonic history in contrast with the Western and Eastern belts. In the south, however, such contrasts are not so clear, as pointed out by Herbert (1983). Rocks included in this belt encompass the previous Cofanes Group and parts of the previous Ambuquí, Llanganates and Zamora Groups.

Whilst it is convenient to erect an informal Central belt at this stage of the project it must be appreciated that this is only a provisional grouping of rocks and further studies will undoubtedly lead to more complex stratigraphic and structural subdivisions. Such subdivisions are already indicated by the lithological changes south of Guamote-Macas; the presence of the less-deformed skarn sequence and associated Azafrán calc-alkaline plutonic chain; and the occurrence of serpentinite blocks in the Río Guachalá, near Cayambe, and Río Chalpi, east of Papallacta (P. Duque, pers. comm.). These latter rivers drain areas lying far to the east of the projected Peltetec subduction sequence (Map 1) and almost certainly are derived from undiscovered serpentinites within the Central belt.

2.4.2 Metasedimentary and metavolcanic rocks north of Guamote-Macas

For the most part, the schists and paragneisses across the geotraverses of the Central belt (Pimampiro-La Bonita, Papallacta-Baeza, Salcedo-Tena, Baños-Puyo and Licto-Huamboya) exhibit similar lithologies, metamorphic grade and structural history. Garnet, biotite and muscovite are prominent metamorphic mineral along with chloritoid; whilst kyanite is found infrequently in late veins. The chrome mica, fuchsite, was also noted sporadically on most of the geotraverses. These minerals are generally related to a steeply-dipping second penetrative schistosity (S₂), in places refolded by later deformation phases. Amphibolite dykes have also been noted.

In the extreme north, around Pimampiro, metavolcanic greenschists are followed to the east by metapsammites and pelitic-schists (chloritoid-garnet-kyanite) which pass into semi-pelitic paragneisses. Over this sector S2 is refolded by open vertical D3 folds and a sub-horizontal D2 tectonic regime is indicated. Further east, acid metavolcanic sericite-rich schists enter the sequence. Between Papallacta and Baeza the traverse is dominated by a semi-pelitic sequence of quartzites, graphitic schists and grey or greenish quartz-albite-muscovite schist with or without chlorite, chloritoid, biotite, epidote, garnet and kyanite. This geotraverse is the most structurally complex, due to the presence of an S3 cleavage, which is of crenulation type in the east changing to a penetrative fabric in the core of the traverse where it forms an S3 "flat belt". On the Salcedo-Tena traverse greenstones and greenschists are intercalated with garnet-quartzites, pelitic and graphitic schists and quartz-feldspar augen paragneisses along the Río Anatenorio before passing into semi-pelitic paragneisses along the Río Mulatos. Between Baños and the Azafrán Granite, the schists are essentially semipelitic rocks with prominent garnet and chloritoid. There is blue quartz in these rocks close to the Baños Front and concordant amphibolites were also noted. Similar rocks were noted on the Licto-Huamboya traverses. The Baños- Azafrán sequence is interrupted tectonically by a slice of low grade graphitic phyllite near Río Blanco.

Apart from the Río Blanco rocks, low grade metasediments also occur SE of a tectonic hiatus, particularly notable on LANDSAT imagery, which crosses into Colombia north of La Bonita. There phyllites and psammites along with metagreywackes and metaconglomerates are also notable in possessing only one penetrative cleavage.

The Guamote-Macas traverse marks the southward transition from 'schist' to 'phyllite' grade along the Cordillera Real. Only a small sector of the traverse is composed of pelitic schists and quartzites (with garnet) and psammitic gneisses (Map 1). Between these rocks and the Baños Front there are pale-green metalavas and banded metatuffs with green and black quartzites and phyllites. To the east there is a sequence of quartzites/greywackes (with clastic blue quartz), graphitic phyllites, pelitic phyllites, meta-acid lavas/tuffs and a hard black graphitic/ ferruginous metasiltstone with total Fe values up to 4.45% (see Nos 17- C, 121-B, 122-C, 122-D, Appendix 1). The symmetrical disposition of these units along the traverse suggests the presence of large-scale D1 folds, upright in the west with a subparallel penetration S2, but subhorizontal in the Río Abanico area, where S2 folds the So/S1 banding.

A later visit by Ivan Verset (INEMIN-Belgium Mission) to the black metasiltstone locality of the Río Abanico, located a fossiliferous float sample containing forms with the appearance of tentaculoids (Ordovician- Devonian).

2.4.3 Metasedimentary and metavolcanic rocks south of Guamote-Macas

These can be provisionally grouped into the following three divisions as follows:

- (a) Zumba gneiss and schist division.
- (b) Loja phyllitic semi-pelite division.
- (c) Guarumales greenschist division.

2.4.3.1 The Zumba gneiss and schist division has been located to the south of the Loja-Zumba geotraverse, north of Loja, and east of Sabanilla, towards Zamora. Map 1 shows the Zumba and Sabanilla outcrops interpreted as a continuous belt.

The division comprises medium- to coarse-grained quartz-feldspathic biotite (muscovite) gneisses, pelitic schists and quartzites; with pegmatitic migmatite zones in the south where the gneissic rocks indicate both para- and ortho-affinities, the latter in the form of xenolithic tonalitic gneiss. East of Sabanilla, the Zumba division contains sillimanite, cordierite, andalusite and garnet (Trouw, 1976) and it is probable that these minerals relate to the contact metamorphic effects of an irregular but largely buried tonalitic-granodiorite intrusive.

Whilst in the Sabanilla-Loja section there exists the possibility that the gneissic rocks are related to the intrusive phases as higher-grade equivalents of the Loja phyllitic semi-pelite division, in the other sectors there are points of evidence which indicate otherwise:

- (a) North of Loja, the Zumba division is cut by the San Lucas Pluton.
- (b) The Zumba division around Zumba and north of Loja possesses a penetrative fabric representing at least the second phase (D2) of deformation, axial planar to Andean-trending steep minor isoclinal folds. This deformation style is different (more complex) than that of the surrounding Loja division over which only the first cleavage is penetrative.
- (c) Amphibolite bands are prominent in the gneissic sequence.

2.4.3.2 The Loja phyllitic semi-pelite division is the dominant metamorphic unit in the south of the Cordillera Real. It is a monotonous sequence of generally impure quartzites; metasilstones; phyllites, graphitic in places; slates; and occasional metagreywackes. There is a general overall absence of greenish rocks of metavolcanic affinities. Chloritoid-bearing phyllites have been noted. In the northern geotraverses (Gualaceo-Limon and Paute-Méndez), rocks close to the Sub-Andean front comprises graphitic and pelitic phyllites, green phyllites and black metasilstones; the latter similar to rocks to the east of the Guamote-Macas traverse.

In the south the Loja division is marked by only one penetrative cleavage (S1), generally steeply-dipping, Andean-trending, and subparallel to bedding; refolded by a steep S2 crenulation cleavage axial planar to tight minor folds. In the north, S2 becomes more penetrative and there are limited S1 'flat belt' zones.

2.4.3.3 The Guarumales greenschist division is found to the east of the Baños front in the south of the Cordillera Real as far as the Guamote-Macas geotraverse (2.4.2). Lithologies are marked by diagnostic green schistose rocks of volcanic affinity associated with black graphitic phyllites, quartz schists, albite greenstones/greenschists and quartzites, in places with clastic blue quartz. They are thus not dissimilar to the Alao greenstone and metasedimentary division of the Western belt found to the west of the Baños front. On the Paute-Méndez geotraverse, lithologies close to the Baños front contain garnet and possibly sillimanite.

2.4.4 Plutonic and meta-plutonic rocks

The geotraverse studies have encountered new plutonic and meta-plutonic bodies within the Central belt some of which, even at this early stage, can be related to new plutonic chains along the cordillera. The following provisional division can be made:

- (a) The “blue quartz” biotite meta-granite chain.
- (b) The Azafrán calc-alkaline chain (variably deformed).
- (c) Other meta-plutonic bodies.
- (d) Other undeformed plutons.

2.4.4.1 The “blue quartz” biotite metagranite chain has been noted along four geotravverses:

- (a) At Papallacta Village, demonstrated by Ing. Duque, there are sillimanite-bearing, coarse grained, blue quartz metagranites.
- (b) To the south at Baños, blue quartz-bearing schistose metagranites, with blue quartz veins, were noted along a narrow section immediately east of the Baños front.
- (c) East of the Baños front towards El Placer (Licto-Huamboya), there is ca. 5 km of slightly deformed blue quartz metagranite and schistose metagranite.
- (d) Near Sigsig, and exposed in the Río Santa Bárbara near to Peggy Mine are outcrops of massive biotite-bearing blue quartz granite and deformed schistose gneiss which also contains blue quartz.

In some of the metagranitic rocks there are conspicuous grey or smoky feldspar megacrystals up to 4 cm long.

North of Papallacta, there are similar biotite-porphyroblastic metagranites, but without the blue quartz: as float blocks in the Río Guachalá (personal observation) draining the metamorphic rocks of the Cayambe volcano slopes; and as extensive outcrop along the Colombian border. In this latter sector (Tulcán-La Bonita) there are three metagranites within the schist/paragneiss host. The most westerly (Sacha) is medium-grained whilst the others (Chingual and La Bonita) are coarse grained with porphyroblastic biotite orientated along the steep foliation which corresponds to S₂ in the schists. The southern contact zone of the Chingual body is marked by ca. 100 m of hornblende-porphyroblastic amphibolite.

2.4.4.2 The Azafrán calc-alkaline chain is a term applied to the extension, north and south, of the Azafrán plutonic suite, previously only noted at Azafrán on the Baños-Puyo traverse.

Along the road section the Azafrán "Granite" (in appearance resembling a leucocratic quartz monzonite) was found to be associated with diorite, a lithology which dominates the float rocks in the adjacent Río Verde. The rocks in this sector are either fresh, with little deformation, or gneissose.

Further north, the Azafrán chain is represented in the Río Mulatos by granodiorites, with mafic igneous xenoliths, and lesser diorites, monzonites, gabbros and granites. These rocks show selective gneissification along discrete shear zones which were also noted in adjacent mylonitic paragneisses.

To the south of Azafrán, metadiorite float was noted at the eastern extremity of the Licto-Huamboya traverse. Further south, along the Guamote-Macas geotraverse, a large calc-alkaline plutonic complex is indicated by river float south of the road west of the Río Abanico. Undeformed xenolithic granodiorite predominates with lesser diorite, gabbro and dolerite, which also outcrops on the road, cutting the country rock phyllites.

From these occurrences, a calc-alkaline chain with Andean trend can be postulated lying immediately west of the Sub-Andean front. Further support for a unified plutonic chain comes from the common presence, at Río Mulatos, Azafrán and Río Abanico, of blocks of an unusual hornblende-porphyritic gabbro, in some cases with rounded hornblende crystals up to 1 cm across.

2.4.4.3 Other meta plutonic bodies, which cannot, as yet, be linked to the above-mentioned plutonic chains, include:

- (a) In the extreme north, the Pimampiro meta-plutonic body (K-Ar age of 72 Ma, Table 2): a hybrid rock, with mafic igneous xenoliths, and containing hornblende porphyroblasts as well as muscovite-biotite clots aligned along the regional S₂ fabric. Further east, close to La Bonita, there is a small stock of metadiorite which shows considerable mylonitisation.
- (b) Tonalitic orthogneisses have been tentatively identified associated with the Zumba gneiss and schist division. The "Palanda tonalite" of ca. 180 Ma (Table 2) probably represents a sector of these rocks.

2.4.4.4 Other undeformed plutons observed along the geotraverses, and which cannot, as yet, be related to the above-mentioned chains, include the southerly plutons of San Lucas, Río Mayo and Zamora, all of calc-alkaline affinity. The San Lucas pluton comprises tonalite-granodiorite with lesser granite and diorite phases. Its K-Ar geochronology gives 50-70 Ma (Table 2). The Río Mayo pluton is a N-S elongate body of similar composition in the extreme south. The Zamora 'batholith' has not been studied, but reports indicate the presence of a calc-alkaline intrusive complex.

2.4.5 Minor intrusions

2.4.5.1 Quartz veins are common throughout the metamorphic rocks of the Central belt and, in general, are parallel to penetrative tectonic surfaces S1 and S2; with S3 quartz veins prominent over the Papallacta- Baeza traverse. The veins rarely exceed 1 m in thickness. Thicker quartz veins, which may also be concordant to schistosity, may relate to later, more brittle, movements.

2.4.5.2 Igneous veins are also common in certain sectors, and many granitoid types can be related to marginal phases of adjacent late plutons, e.g. the Río Mayo pluton (Loja-Zumba). Other cross-cutting types can be linked to Cenozoic volcanic activity. True (folded) migmatitic veins have only been noted in the Zumba gneiss and schist division.

Small, late, pegmatites, tourmaline-bearing in places, found at Azafrán, Loja-Zumba, near the Río Abanico and near Pimampiro, can be related to nearby calc-alkaline plutons. There are local swarms of felsitic dykes, up to 40 m in dyke-thickness, and bodies, which appear to be late-tectonic with respect to the local S2 schistosity; they are concordant and many possess foliated margins. The dominant compositional type is a leucocratic quartz micro-monzonite, but granites, aplogranites and porphyries have also been noted. Such swarms are particularly prominent in the greenschist belt near Pimampiro, in the gneisses north of La Bonita and along the eastern sector of the Guamote-Macas traverse where they are associated with small pegmatites and found close to small granodioritic and aplogranite bodies. Again, it is probable that these swarms are related to the late-tectonic emplacement of adjacent calc-alkaline plutons.

2.4.6 “Exotic” block lithologies

These refer to lithologies found as loose blocks but not seen in outcrop; only those considered of major significance are mentioned below.

2.4.6.1 Serpentinite blocks have been found in the Río Guachalá near Cayambe town (Sauer, 1965 and personal observation); these are clearly derived from the east and the metamorphic float association (paragneisses, schists and blue quartz metagranite) would indicate a derivation from the Central belt.

Serpentinities have also been noted in the Río Chalpi (P. Duque, pers. communication) which drains from the north into the Río Papallacta about 6 km east of Papallacta village. Further downstream near Baeza serpentinites have also been reported by Colony and Sinclair (1932). It is possible that the Chalpi and Guachalá serpentinites are derived from the same source ?ophiolite belt.

2.4.6.2 Blocks of skarn rock, with other 'exotic' types, were found in the Río Mulatos (Salcedo-Tena) and in rivers and streams draining from the west. The following lithotypes were noted (see analyses, Appendix 1):

- (a) Pale skarn with free carbonate: these normally possess green epidotic tints and magnetite veins and may also carry garnet and randomly-orientated amphibole crystals. They show prominent carbonate veins with asbestiform amphibole.
- (b) Black skarns: of essentially quartz-epidote-magnetite-amphibole-garnet composition. These are generally heavily mineralised giving a grey metallic luster to the river-worn blocks.
- (c) White-grey cherts and green laminated calcareous tuffs intercalated with (a).
- (d) Mineralised black ferruginous phyllites, and black biotitites, the latter probably derived from biotite rich selvages in calcite veins in adjacent gneissified calc-alkaline plutons.
- (e) Undeformed, slightly metamorphosed, basalt lavas with pillow structures tentatively identified.

The skarn minerals in these rocks can be related to adjacent calc-alkaline plutonic rocks of the Azafrán chain. It is interesting to note that, structurally, the blocks exhibit discrete gneissic zones similar to the adjacent plutonic bodies. Both lack the regional penetrative deformation found in the adjacent schists and paragneisses of the Central belt.

2.4.6.3 Other exotic blocks: rivers draining the contact zone between the Sacha pluton and the paragneisses to the west (Tulcán-La Bonita) contain blocks of basic metalava and ultramafic tremolite schist.

2.5 The Sub-Andean Front

The Eastern belt of "semi-metamorphic" rocks, some of which are recognisable Cretaceous formations of the lowland platform, is separated from the Central Belt by a tectonic line which is referred to here as the Sub-Andean front. The approximate location of this line is well known (Tschopp, 1953; Baldock, 1982) but its exact position is not defined due to the inaccessibility of the terrain; the various lithological and tectono-metamorphic parameters utilised for distinguishing it; and the fact that the "transition zone" may comprise more than one zone of "thrusting". To overcome these difficulties the Sub-Andean front is provisionally defined as the change from the westerly metamorphic complex of the Central belt into lower grade, structurally less complex units of the Eastern belt which can be correlated with Jurassic-Cretaceous formations of the lowland platform. This definition allows both for an older Central belt or a craton: mobile belt tectono-metamorphic transition, as suggested by Feininger (1975).

Over the first year's geotraverses, the Sub-Andean front has been most clearly recognised as the sudden eastward change, along the Río Mulatos, from rocks of the Azafrán calc-alkaline chain, gneissose in places, to weakly-deformed acid lavas and Napo Formation rocks: a change ca 8 km further west than that indicated on the national geological map (Baldock, 1982). It must be pointed out that, for the Río Mulatos section at least, this important structure has no clear expression on LANDSAT, although further north it probably links up with a lineament which truncates an igneous ?ring complex north of the Río Valle Vicioso from where it can be traced to the Papallacta-Baeza traverse. To the south of the Río Mulatos the Sub-Andean front has been delimited in the field with varying degrees of precision and subjective interpretation on the following geotraverses: Baños-Puyo, Guamote-Macas, Paute-Méndez and Gualaceo-Limón. Details are found in the following section (2.6).

2.6 The Eastern Belt

As previously noted, (2.5), the Eastern Belt comprises "semi-metamorphic" rocks between the Central Belt and the lowland platform of the Oriente. Previous work has shown that within this belt there probably exists tectonic "slices", some of which can be identified as lithostratigraphic formations of the lowland platform, e.g. the Cretaceous Napo and Hollín formations. Some workers, e.g. Tschopp (1953), have indicated that older units, e.g. the Chapiza (Jurassic), Macuma (Carboniferous) and Pumbuiza (?Devonian) Formations, may also be present. These units of doubtful affinity have been included into the Margajitas Formation (?Paleozoic-Mesozoic) by Baldock (1982). Within this Eastern belt lies the Abitagua granite batholith dated at ca. 180 Ma, but, according to Mortimore and Malo (1980), with intrusive contacts against Cretaceous formations.

The following description of the belt are derived from the first year's geotraverses, from north to south:

2.6.1 *Papallacta-Baeza*

On this section, the change from the Central to the Eastern belt (i.e. the Sub-Andean front) can be postulated west of Baeza, about 2 km west of the Quijos/Huagrayacu confluence. The change, across an exposure gap, is from schists with two penetrative schistositys in the west, to cleaved, greenish-grey siliceous quartz-chlorite-albite metavolcanics with deformed volcanoclastic fragments. These rocks possess a steep Andean- trending S1 cleavage cut by a steep S2 crenulation cleavage axial planar to minor folds verging east. Near Baeza, there are cleaved purplish phyllites with the same tectonic history. Outcrops and blocks of graphitic phyllite and black limestone were noted in streams near Baeza which may represent the Napo Formation. The contrasting tectonic history across the proposed Sub-Andean front is important since, greenschists, not dissimilar to those of the Eastern Belt, crop out in the Central belt along the road to the west. Indeed, this sector is the least convincing in terms of lithological contrasts across the front, though further work over this same region by Van Thournout and Piedra (1986) indicated a major tectonic break west of Baeza.

2.6.2 *Río Mulatos (Salcedo-Tena)*

As previously mentioned, this section is probably the most convincing transition from the Central to the Eastern belt. Leaving the rocks of the Azafrán calc-alkaline chain one is confronted with cleaved, dark greyish-green silicic lavas and pyroclastics which, towards the Abitagua granite, lose all signs of tectonic deformation. The undeformed lavas are pale, black, glassy or pink porphyritic silicic types associated with flow breccias and pyroclastics. There is an intervening belt of fossiliferous black cleaved limestones, calcilutites and phosphate rocks with a W-dipping Andean-trending cleavage axial planar to folds plunging at ca. 40 to the SSW. Blocks of black mudstone, chert, and fine-grained yellow, purple and red sandstone were also noted. A provisional interpretation correlates the carbonate rocks with the Napo Formation, owing to the presence of diagnostic phosphate beds (Wilkinson, 1982), and the volcanics with the Misahuallí member of the Chapiza Formation (Jurassic).

Close to the Abitagua Granite contact the volcanic rocks are interrupted by a granite outcrop in the river (no contacts were seen); there is also an in-situ outcrop showing a narrow zone of feldspathisation. On this basis the Abitagua Granite is provisionally regarded as intruding a Misahuallí volcanic envelope. The western margin of the Abitagua Granite, as seen in the Río Mulatos, comprises an outer shell of medium-grained xenolithic hornblende-biotite granite and a younger inner shell of coarse-grained K-feldspar megacrystic biotite granite.

2.6.3 Baños-Puyo

On this section there is an exposure gap following the most eastern outcrop of the Azafrán monzonite which intrudes schists with two penetrative cleavages. Outcrops east of the gap exhibit greenish metavolcanics, blue quartz metagreywackes, pelitic phyllites and graphitic phyllites all of which possess one penetrative cleavage only. Blocks in the Río Topo, derived from this belt, also comprise undeformed fossiliferous black limestones, black mudstones with pyrite concretions; and a pre-tectonic breccia containing angular fragments of Azafrán monzonite in a black cleaved porphyritic volcanic rock. Thus, the Sub-Andean front is drawn east of the Azafrán monzonite dividing rocks of differing tectono-metamorphic history.

The Abitagua Granite on the Baños-Puyo section is undeformed and exhibits a western K-feldspar megacrystic margin (2 km) and an equigranular coarse-grained biotite central phase. Volcanic dykes and xenoliths are present in places; one compositional type being micro-monzonite.

2.6.4 Guamote-Macas

Along this geotraverse the Sub-Andean front is drawn east of the Río Abanico enclosing the hill-range of low-grade black metasiltstones within the Central belt. Further east, there are blocks of conglomerate, with black metasiltstones clasts, and the low W-dipping, undeformed, hills of Macas formed of the Cretaceous Hollín Formation.

2.6.5 Paute-Mendez

Here the Loja phyllitic semi-pelite division is succeeded eastwards by a belt of phyllites and black metasiltstones, provisionally included in the Central belt, followed by conglomerates (with metamorphic clasts), black limestones and calcilutites (probably the Napo Formation) and quartzite (Hollín Formation). Cleavage is poorly developed in these rocks.

2.6.6 Gualaceo-Limón

On this geotraverses, following eastwards on the Loja phyllitic semi-pelite division, which contains two penetrative cleavages, there are five narrow tectonic zones attributed to the Eastern belt, viz:

- (a) Metatuffs and felsic volcanics (ca 500 m)
- (b) Mylonites (ca 1 km)
- (c) Graphitic phyllites and ?amphibolites (ca 1 km)
- (d) Metavolcanics (ca 1 km)
- (e) Low-grade slates with fossils (?Napo Formation)

The metavolcanic fraction is tentatively assigned to the Misahuallí Member of the Chapiza Formation.

2.7 Discussion

An attempt has been made in this section to summarise the geology of the first year's geotraverses and propose informal lithological and tectonic subdivisions as a framework for the future. However, whilst the studies mark an advancement in the understanding of the metamorphic rocks, there are still insufficient constraints for the proposal of models to account for the geological history of the area. Further geotraverses, specific structural investigations, palaeontological studies and the geochronological programme are all required before this stage can be reached.

The following sections, discuss the possible significance of the new discoveries and also dwell on the problems that remain to be solved.

2.7.1 The Western Belt

The identification of the Western belt and the Peltetec subduction complex enables rocks, previously assigned to differing lithostratigraphic units, to be reassessed, and opens up the possibility of regional correlation with Colombia and the El Oro Province. Furthermore, its identification will be crucial to the understanding of the main Central belt since the subduction complex will enable the proposal of plate tectonic models to account for the geological history further east.

Added to this there is the geotectonic significance of the Peltetec 'line' during the later evolution of the Ecuadorian Andes.

2.7.1.1 The nature of the Western belt has already been a subject of speculation (Aspden et al., 1987) and the lithological divisions at Peltetec have been tentatively interpreted as follows:

- (a) Guamote quartzite division: continental molasse
- (b) Cebadas black phyllite division: pelagic sediments
- (c) Peltetec subduction complex: oceanic crust/fore arc sediments
- (d) Alao greenstone and metasedimentary division: island arc/?back arc sequence.

The older continental rocks west of Cuenca (Lebrat et al., 1986) which underlie the Macuchi/Celica Formation could represent a slice of the western continent which collided to close the Peltetec oceanic/marginal basin. However, it must be noted that tectonic slices of blue quartz/smoky feldspar metagranite found structurally beneath the E-dipping subduction complex are similar to the metagranites east of the Baños front. This, along with the regional evidence for horizontal D1 folding, raises the possibility that the Western belt represents a Himalayan-type nappe complex extending westwards from the Baños front.

2.7.1.2 Correlation with Colombia has also been indicated (Aspden et al., 1987), linking the Peltetec subduction complex with the ca. 120 Ma Romeral Fault, related to a common collision sequence (Amaime oceanic terrane and Western belt) prior to the accretion of the Western Cordillera along the ca. 60 Ma Cauca-Patía/Calacalí-Pallatanga suture (Aspden et al., 1987); thus proposing the outward growth of the South American continent by successive accretions.

2.7.1.3 Correlation with the El Oro metamorphic belt has yet to be field tested, but the most obvious exit for the Peltetec complex is via the Jubones Fault, with the rocks to the south, as far as the Raspas ophiolite and blueschists, being correlatives of the Western belt.

2.7.1.4 Geotectonic implications for the Ecuadorian Andes are indicated by a glance at the LANDSAT scenes of the Inter-Andean graben. The line of the Peltetec complex can be seen to control the eastern fault of the graben (Río Chambo lineament) and the Cenozoic volcanic activity (Altar, Tungurahua, Cotopaxi) in the same way that the younger Calacalí-Pallatanga suture controls the western fault. Thus, the Peltetec “suture” has been a fundamental line of weakness throughout the Cenozoic history of Ecuador.

2.7.2 The Baños Front

Whilst this structure marks the eastern limit of the Western belt its significance remains a subject for speculation. Basically, there are two lines of approach:

- (a) The Baños front is an exposed older continental margin.
- (b) The Baños front is a fundamental structure reflecting an older continental margin at depth.

The first of these (a) would place the metasedimentary and metavolcanic rocks of the Central belt as older than those of the Western belt and part of an older ?Paleozoic continental margin sequence; the second (b) would identify these same rocks as the uplifted and intruded backarc basin to the Peltetec subduction sequence. Below, various points of evidence are discussed in the light of these two possibilities.

- (1) The blue quartz metagranites are found immediately to the east of the Baños front; similar metagranites further east (Tulcán- La Bonita) do not carry blue quartz. Does the blue quartz indicate the excavation of deep crustal granulite facies rocks along the Baños front? (P. Duque (pers. comm) reports the high-grade mineral sillimanite from the Papallacta metagranite). If so these could be older granulites (a) or Mesozoic ones (b) related to local Himalaya-type underplating. However, the blue quartz may relate merely to cataclastic effects along the front. This alternative fits better for the Sigsig outcrop where the blue quartz granite is intruded into low-grade green phyllites of the Guarumales division.

- (2) The natural exit for the Baños front in the south is through the Raspas Formation of the El Oro Province. Here again there are deep crustal high-pressure rocks in the form of blueschists.
- (3) Structural studies across the Baños front have, so far, not revealed significant changes in tectonic history vis-a-vis polyphase deformation. Clearly if the front marks an exposed older continental margin (a) one would expect to find, to the east, older structures overprinted by those related to the Peltetec collision from the west. In this respect, it is noteworthy that a second penetration cleavage (S₂) appears to be developed north of a certain latitude in the rocks on both sides of the Baños front indicating the possibility of some form of tectonic cohesion.
- (4) There are late-tectonic (late-S₂) micro-monzonite dykes in both the Western and Central belts. If these are the same age, theory (b) would be supported.
- (5) Greenstones/greenschists are found either side of the Baños front at Ambuquí-Pimampiro, Guamate-Macas, Paute-Méndez, Cuenca- Limón and Sigsig-Chiguinda. In the north there is a marked difference in metamorphic grade and lithological association across the front, but in the south, this is not so clear-cut. Are these green rocks the same unit (b)? Or are those to the east older (a)?

2.7.3 The Central Belt

The following points are noteworthy in terms of this, the most geologically complex, of the three belts:

- (a) The Zumba gneiss and schist division is the most favored candidate as an older, possibly Precambrian, basement. The presence of migmatites, and its more complex structural history suggests a basement: cover relationship with respect to the adjacent Loja phyllitic semi-pelite division. Thus, the Central belt in the south may rest on ensialic basement, as indicated by the Peruvian studies (Laubacher and Megard, 1985). In contrast, Precambrian relics are not thought to be present along the Colombian border to the north (cf. Feininger, 1982); in the sense that no high grade migmatitic or granulitic rocks were noted.

- (b) Whilst certain age relationships have been determined in the Central belt, no conclusion have yet been reached regarding the age of the metasedimentary and metavolcanic rocks. Correlation of lithotypes along the belt is not helped by the general lack of marker bands or sequences which could be traced from one geotraverse to another. However, it can be suggested that the Guarumales green phyllite division of the south is represented in the north by the greenschists found close to the Baños front near Pimampiro and also in the Papallacta-Baeza section. The schists and paragneisses of the Central belt in the north are also regarded as a lithostratigraphic unit in terms of tectono-metamorphic history and lithotypes; chloritoid-garnet-and fuchsite-schists being characteristic. A characteristic blue-grey meta-psammite was noted along both the Tulcán-La Bonita and Guamote-Macas traverses, and this kind of correlation is the most useful.
- (c) However, Guamote-Macas represents the transition in metamorphic grade, e.g. absence of regional metamorphic garnet in the rocks to the south (with the exception of the Zumba "basement"). This could be explained by south-plunging isograds: a phenomenon which could also account for the greater abundance of deep-seated metaplutons in the north.
- (d) There also exists the possibility that the Central belt bifurcates over the critical region south of Guamote-Macas. If Palaeozoic rocks are assumed, based on data from Colombia and Perú, then it is possible that the Upper Palaeozoic El Oro rocks (south of Raspas) could link up with the rocks of the south-Central belt. In this respect it is pertinent to note that the Loja semi-pelitic division has not been satisfactorily traced to Guamote-Macas. In the final synthesis, a lot will depend on if and how the rocks of El Oro are correlated with those of the Cordillera Real.
- (e) It has already been stressed that the term "Central belt" is provisional, especially with regard to the identification of 'exotic' serpentinite blocks draining from it. The following sequence of events in the north can be cited as further evidence of a multiphase "orogenic" (sedimentary-plutonic) history:
 - (1) Regional metamorphism to form schists and paragneisses accompanied (syn-D2) by the intrusion of the meta-granite chain, blue quartz-bearing along the Baños front.
 - (2) Followed by: deposition of carbonates, lavas etc. (skarn blocks); the intrusion of the Azafrán calc-alkaline chain; and the local mylonitisation/ gneissification of these rocks.

- (f) One interesting feature of the Azafrán chain is the apparent absence of the selective mylonitisation/gneissification in the loose blocks of the Abanico pluton (Guamote-Macas) in the south. This, and the calc-alkaline association, leads to the speculation that the Azafrán chain may extend further south to encompass the undeformed calc-alkaline plutons of Río Mayo and Zamora, leading to further speculation that the Nambija gold skarns may be related, both in age and paragenesis, to the Llanganates (Río Mulatos) skarns.

2.7.4 The Eastern belt and Sub-Andean front

The Eastern belt of rocks is thought to be correlatives of Phanerozoic formations identified over the lowland platform (Tschoep, 1953), and this has been largely confirmed by the geotraverse studies. However, metamorphic units such as black marble and black phyllites are not necessarily diagnostic of a particular Palaeozoic/Mesozoic formation of the Oriente, whilst the apparent tectonic slicing within the Eastern belt, accompanied by cleavage formation, effectively rules out the identification of “type” stratigraphic columns.

With regard to the correlation of ‘orogenic’ events across the Cordillera Real, it is important to note the stratigraphic breaks in the rocks of the lowland platform of the Oriente (Tschoep, 1953). These occur below and above the Macuma Formation (Upper Carboniferous); and with marked unconformably between the Santiago Formation (Lower Jurassic) and Chapiza Formation (Middle-Upper Jurassic); and between the Chapiza Formation and Hollín Formation (Lower Cretaceous). Assuming that these latter unconformities were registered as tectono-metamorphic events over the Cordillera Real then dates of around 180 Ma and 120-140 Ma should be expected; in addition to the ca. 50 Ma dates which should coincide with the ‘thrusting’ (or last phase of movement) along the Eastern belt involving the Hollín, Napo and Tena (Upper Cretaceous-Lower Palaeocene) Formations, a date which roughly coincides with the Calacalí-Pallatanga collision suture situated west of the Western belt.

2.8 Conclusions

A lithological and tectonic framework has been established for the elucidation of the geological history of the Cordillera Real. This framework awaits geochronological, palaeontological and further geotraverse studies (including the El Oro Province) before serious interpretations can be made.

Although two fundamental tectonic fronts have been identified separating three belts of rocks the full significance of these fronts is not yet appreciated; whether they separate rocks of different ages or different orogenic environments is not yet clear.

What is clear is the complexity of the Phanerozoic history of this Andean section and the need to elucidate the sequence of operative processes so that the mineral potential of the area can be fully understood.

3. MINERAL OCCURRENCES AND GEOCHEMICAL ANOMALIES

In this section the mineral groupings follow those of the Mining Journal. Only mineral occurrences and geochemical anomalies found by the Project are noted here. These are integrated with previous mineral discoveries under Chapter 4.

3.1 Precious metals

3.1.1 Gold

The gold potential of the geotraverses has yet to be evaluated. This awaits analyses of the heavy mineral separates collected at most geochemical stations.

Rock analysis of certain of the black skarn blocks from the Río Mulatos yield gold values up to 15 gm/tn. The importance of this new "Llanganates gold belt" is discussed under 4.1.

A pilot examination of alluvial and in situ gold from Ecuador has been made by B. Beddoe-Stephens (BGS, Edinburgh) and is enclosed as Appendix 3 of this report. The report covers alluvial gold samples from the entire country including six samples from rivers draining the Cordillera Real (JACR Nos. 4-10). Samples JACR 1, 18 and 19, of primary gold samples from Nambija/Guaysimi, are discussed in 4.1.

Anomalous arsenic values up to 126 ppm in fluvial samples B30, B31, B33 and B34 collected west of the Río Abanico (Guamote-Macas) may relate to gold mineralization from the Abanico calc-alkaline plutonic complex to the south.

3.1.2 Silver

Silver values in the Río Mulatos skarns reach 22 gm/tn and they are relative to corresponding gold values (Appendix 1).

Silver values up to 18 gm/tn are found in small veins of copper mineralization related to the Peltetec subduction complex (Appendix 1). Previously identified silver mineralization is discussed in "Baños front related mineralization" (4.2).

3.1.3 Platinum

Appendix 3 contains a report on alluvial platinum grains from the Río Camumbi, Carchi Province, outside the Project area.

3.2 Older major metals

3.2.1 Copper

From north to south copper mineralization and geochemical anomalies have been noted at the following localities.

- (a) Small Cu mineralization altering to malachite associated with the Pimampiro meta-pluton.
- (b) A float block of vein quartz with azurite was noted in the Río Sardinas Chico (Papallacta-Baeza). Further investigation by an INEMIN economic brigade (Van Thournout and Piedra, 1986) traced this mineralization to a 5 km long "greisen" zone with small Cu-Zn mineralization within meta-andesites, probably corresponding to the Misahuallí Member.
- (c) Copper sulphides were noted in various outcrops and loose blocks in the Río Mulatos (Salcedo-Tena). These include the pale skarns, the heavily mineralized black gold-bearing skarns, biotite schists and paragneises. However, rock analysis shows Cu values only as high as 273 ppm (Appendix 1), whilst fluvial samples (Appendix 2), though showing anomalous Cu over this sector (samples B42-B47), reach a maximum of only 157 ppm.
- (d) Small Cu-Zn veins occur in the gneisses and schists near Agoyán tunnel (Baños-Puyo), and chalcopyrite/bornite disseminations were noted in schists close by.
- (e) Small Cu veins were noted in the serpentinite and adjacent rocks (black cherty quartzites, black lutites) of the Peltetec subduction complex at Peltetec-Huarguallá. In one sample the Cu value attains 5% (Appendix 1).
- (f) On the Licto-Huamboya traverse there are numerous concordant quartz veins carrying small chalcopyrite-Pb-Zn mineralization over the watershed region close to the Baños front.
- (g) On the Guamote-Macas traverse, there are small chalcopyrite disseminations in the greenstones near Laguna Atillo, and in small quartz veins in the black metasiltstones near the Río Abanico. There is also a quartzite "metagreywacke"/acid meta-volcanic horizon with high sulphide content (up to 5%) found at four localities along the section. These occurrences have been provisionally interpreted as a single folded formation. It is possible that the mineralization is stratabound. However, the copper content is only 252 ppm (Appendix 1). A copper anomaly of 125 ppm occurs over this sector.
- (h) On the Paute-Méndez traverse there is a vein of massive pyrite with chalcopyrite/bornite in the Guarumales greenschists. Cu content only reaches 231 ppm (Appendix 1). There is a copper anomaly of 181 ppm draining metavolcanic phyllites further east on the same traverse (Appendix 2).
- (i) East of Catamayo, there are small quartz veins carrying chalcopyrite within the Loja semipelitic division.

3.2.2 Lead and zinc

From north to south the following occurrences and geochemical anomalies have been noted:

- (a) Small quartz veins carrying galena were noted cutting an outcrop of concordant muscovite granite within greenschists near Sigsigpamba (Ibarra-La Bonita).
- (b) On the Papallacta-Baeza traverse indices of galena were noted in float samples from the Río Sardinas Chico (see 3.2.1).
- (c) On the Baños-Puyo traverse Cu-Zn veins were noted near Agoyán (see 3.2.1).
- (d) Sphalerite was noted with copper in small veins cutting black cherty quartzites associated with the Peltetec subduction complex. It is interesting to note the higher Zn value (1700 ppm) in the overlying alteration zone (Appendix 1).
- (e) Sphalerite and galena were noted along with Cu mineralization over the Licto-Huamboya watershed (see 3.2.1).
- (f) There is a geochemical Zn anomaly of 339 ppm corresponding to an arsenic and Cu anomaly (see 3.2.1) along the Guamote-Macas traverse.
- (g) A high Zn anomaly of 2300 ppm (Appendix 2) occurs in the Alao greenstones west of the Amaluza pluton (Paute-Mendez). Another of 625 ppm occurs locally.

3.3 Steel industry metals

3.3.1 Chromium

A small vein of copper mineralization associated with the Peltetec subduction complex gives 1600 ppm Cr (Appendix 1). Close by, there is a geochemical anomaly of 651 ppm Cr from the stream draining the Peltetec serpentinite. The Cr value of the serpentinite rock is 277 ppm.

There is an interesting Cr geochemical anomaly of 422 ppm (Appendix 2) possibly related to the San Lucas pluton (Catamayo-Loja).

The chrome-mica fuchsite was noted in schist specimens from a number of the northern geotraverses across the Central belt.

3.3.2 Cobalt

The highest Co value in rocks analysed is 411 ppm from the “stratabound” sulphide-rich metagreywacke/metavolcanic unit (see 3.2.1).

No geochemical Co anomalies stand out from the results in Appendix 2.

3.3.3 Iron

Apart from minor hematite concentrations in veins, the only interesting Fe concentration occurs in the magnetite skarn blocks of the Río Mulatos where total iron values reach 39% (Appendix 1). These black skarns show magnetite mineralization as veins or disseminations. A study of the source rocks could locate massive vein mineralization; though examination of float samples found no large magnetite blocks.

One ferruginous black metasediment of the western belt shows total Fe of 24% (Appendix 1).

3.3.4 Molybdenum

Small flakes of molybdenite, up to 1 cm across, were noted in quartz veins cutting the southern mafic contact zone of the Chingual orthogneiss along the road to La Bonita.

3.3.5 Nickel

There is a geochemical Ni anomaly of 801 ppm (ca. eight times back-ground) from the stream draining the Peltetec serpentinite (Appendix 2). This is five times the Ni value of the serpentinite rock (155 ppm) (Appendix 1). Chromium is also anomalous at this station (see 3.3.1).

The nickel values for the stream sediments collected on the Loja-Zumba traverse (Appendix 2) cannot be regarded as reliable.

The highest Ni value from rock analyses (742 ppm) comes from reddish weathering material in small quartz veins cutting black phyllites near Ambuquí.

3.3.6 Tungsten

Of those samples analysed the highest W contents come from the Mulatos skarns and associated rocks; the highest value being 1700 ppm.

3.4 Nuclear metals

No scintillometer traverses were undertaken, but all samples collected in the field were examined under a portable gamma ray scintillometer in the office. No anomalously high counts were noted.

3.5 Chemical metals and minerals

3.5.1 Gypsum

Small gypsum mineralization was noted related to kaolin zones (see 3.5.2.) but is of no economic interest.

3.5.2 Kaolin

Kaolin deposits have been noted related to highly-altered felsitic volcanic rocks on the east of the Gualaceo-Limón traverse; and to highly-altered microfeldspathic dykes and sheets. Near Pimampiro on the Monte Olivo road, there is a 20 m highly-altered zone within a 40 m dyke in greenschists. Along the Baños-Puyo traverse there are highly-altered micro-feldspathic dykes in the Abitagua granite. In both these occurrences there is 5-10% fine quartz in the rock. Samples have been submitted to the INEMIN industrial mineral project.

3.5.3 Phosphate rock

A granitoid block rich in apatite was found in the Central belt of the Papallacta-Baeza traverse. The apatites are up to 2 mm in length and comprise about 5-10% of the rock.

A new ca. 50 cm bed of phosphate rock of Napo Formation-type was discovered in the Río Mulatos east of the Sub-Andean front within a sequence of red calcilutites and black shales. The rock is a phosphatic limestone similar to those described by Wilkinson (1982) from elsewhere in the Napo Formation. Red-brown phosphatic pellets up to 3 mm long, occur in a carbonate matrix. The sequence is folded and cleaved, plunging about 40 deg. to the south.

Analytical results for the two phosphate localities are still unavailable.

3.6 Insulants and refractories

3.6.1 Asbestos

The most interesting asbestos discovery is related to the serpentinite at Huarguallá Valley. In the lower 5 m of the E-dipping serpentinite (the most deformed section) slip-fibre chrysotile asbestos forms along movement planes of 1-3 mm spacings. At higher structural levels the serpentinite (5-10 m) is more massive and the asbestos forms in a vein stockwork separating blocks ca 20 x 10 x 10 cm in size. Samples have been submitted to the INEMIN industrial minerals project. Further north, along the Alao road, blocks of the same serpentinite body show small veins containing blue asbestos.

There are small asbestos veins in exotic blocks in the Río Mulatos which have no economic significance.

3.6.2 Graphite

Graphite-rich schists and phyllites were reported from many geotraverses, but it is doubtful if any are of economic significance. The highest-grade occurrences were noted at Papallacta-Baeza, Patate-Baños, Huarguallá Valley, Amaluza-Méndez and Gualaceo-Limón. Samples have been submitted to the INEMIN industrial minerals project.

3.6.3 *Magnesite*

This mineral is found within the asbestos veins in the Huarguallá serpentinite, but not in economic concentrations.

3.6.4 *Sillimanite minerals*

Although kyanite has been noted in the field, and sillimanite in recent petrographic studies, their occurrence is of academic interest only.

3.7 Other industrial minerals, rocks, gemstones and hot springs

3.7.1 *Carbonate*

The Napo Formation limestones occur in the Eastern belt. The remainder of the Cordillera Real presents only thin marble bands within the metamorphic sequences.

Small calcite veins are ubiquitous in the greenstones sequences. These are best developed in the Huarguallá Valley where calcite crystals up to 30 x 20 x 20 cm in size can be collected; but these are not of Iceland spar quality.

Travertine deposits were noted, the largest of which, near Baeza, is five metres thick.

3.7.2 *Clays*

Samples from a 2 m thick alluvial clay sequence near Río Cugusha (Guamote-Macas) have been sent to the INEMIN industrial minerals project.

3.7.3 *Feldspar*

Feldspar-rich rocks occur in the form of plutonic quartz-monzonites (e.g. Azafrán), microfeldspathic dykes and sheets, aplogranites and aplites. It is unlikely that any of these would be of economic interest.

3.7.4 *Garnet*

This mineral, used industrially as an abrasive, is common in the schists and gneisses of the Cordillera Real and frequently is an important constituent of panned heavy mineral separates. However, in terms of economic concentrations, the only possibility lies in the source rock of the Mulatos skarns, since a common fine-grained pink 'pale skarn' type has recently been examined petrographically and found to consist, essentially, of garnet-rock.

3.7.5 *Hot springs*

A small effusion was noted near El Placer (Licto-Huamboya), east of the main known localities (De Grys et al., 1970).

3.7.6 *Mica*

No mica deposits of economic interest have been noted; the pegmatites are too small to yield large mica sheets. In the Río Mulatos there are small blocks of schists with high biotite content.

3.7.7 Quartz

Veins of quartz wider than 1 m are rare. There is a 3 mm vein of fairly pure quartz near Sigsigpamba.

Purplish, bluish, smoky and yellowish tints have been noted in quartz but none of the material is suitable for the semi-precious stone industry.

3.7.8 Slate

Material with potential for roofing slate was noted 4 km west of Baños.

3.7.9 Stone

There are a few stone quarries over the area for road aggregate; gravel is worked from decomposed Abitagua granite. Building stone is rarely used; most dwellings are of adobe. There is potential for ornamental stone; especially the blue quartz/smoky feldspar granites of Peggy Mine (Sigsig). Megacrystic gabbros have also been noted. The Huarguallá serpentinite could possibly be used for ornamental carving.

3.7.10 Talc

There are bands, up to 2 m thick, of white, fine, “talcose” schists within pelitic schists near the Río Cagusha (Guamote-Macas). Samples have been sent to the INEMIN industrial minerals project.

3.7.11 Tourmaline

Schorl (black tourmaline) has been noted in association with small pegmatites. No tourmaline of gemstone grade was seen. One sample from the Río Mulatos contains 25% tourmaline (Appendix 5).

4. REGIONAL MINERAL POTENTIAL

Based on the first year's work of the Project, and pre-existing data, three new Andean-trending mineral belts can be proposed as follows:

- (a) The Llanganates skarn gold belt.
- (b) The Baños front-related Ag-Cu-Zn-Pb belt.
- (c) The Peltetec ophiolite belt.

4.1 The Llanganates skarn gold belt and its possible correlation with Nambija

4.1.1 The Río Mulatos skarns

The skarn rocks and associated 'exotic' blocks from streams and rivers west of the Río Mulatos show the following lithologies.

- (a) Pale skarns
- (b) Black skarns
- (c) Limestones, probably related to the pale skarns
- (d) Cherts, and green calcareous ?metatuffs
- (e) Black 'metalavas', now seen under the microscope to be ultramafic serpentinitic rocks, thus confirming the presence of 'ophiolitic' rocks in the Río Mulatos (Sauer, 1965) but not in the quantity indicated
- (f) Contact metamorphic garnet-megacrystic phyllites (see Appendix 5)

The dominant float lithologies are the pale and black skarns which show provisional gold values from 4 to 15 g/t (Appendix 1); the highest values occurring in the black skarns.

Preliminary petrographic studies recently undertaken in the INEMIN office and in UK (Appendix 5) show the colour difference to be related to iron content. Thus, the colour of the black skarns relates mainly to the presence of iron-rich amphibole (ferrohastingsite) and also to a higher magnetite content. The black skarns also have a higher content of sulphides the weathering of which is attributed to the characteristic metallic luster of the river-worn boulders. Both the magnetite and sulphide mineralization are late, but it is not clear whether the gold is related to one of these minerals or neither.

Both skarn types appear to be distinguished by hedenbergite and grandite garnet (grossular-andradite) as prograde skarn minerals. Thus, the difference in skarn colour may be essentially due to later iron enrichment rather than a higher protolithic iron content. If this is true then the iron must be probably have been derived from the adjacent grano-diorites and diorites, which, it is assumed, were responsible for the skarn metamorphism.

One mystery has now been resolved by recent petrographic studies: the "pale skarn" boulders are dominated by a pink, fine-grained, hard rock in stages of alteration to greenish phases along veins or gneissic zones. Petrographically these "alteration zones" comprise epidote, Fe-poor pyroxene and amphibole, and calcite; whilst the 'pink rock' is not protolith but garnet-rock marking, probably, the first phase of skarn mineralization.

4.1.2 Other skarns of the Llanganates belt

Following the Río Mulatos traverse (above), Merlyn and Cruz (1986) located garnet-magnetite-pyrite-sulphide skarn blocks in the Ríos Aguas Blancas and Paracayacu further south along the same strike as the source rocks of the Mulatos skarns. In situ sub-horizontal marbles (ca. 50 m thick) were also found in the same area overlying a metaplutonic phase with a sharp non-metamorphic contact. It is possible that this underlying ortho-gneiss represents an older plutonic phase in the evolution of the Central belt and that the overlying limestones are the skarn protoliths.

Further north, there are reports of gold-bearing skarns from the Río Chalupas.

To the south there are reports of skarns from the Brunner Concession of the Cerro Hermoso area.

4.1.3 The nature of the Llanganates skarn gold belt

Plotting the Llanganates skarn occurrences produces a rough linear belt trending about 10 deg. east of north, oblique to the regional strike (30 deg.) which is so marked on the LANDSAT images, and is parallel to mylonites in the Río Mulatos. Little is known about this belt with regard to in situ contact relationships. From the Río Mulatos studies it can be suggested that the protolithic rocks of the skarn sequence and other exotic lithologies were not part of the regional gneisses and schist sequence of the Central belt; but were deposited later and then intruded by the Azafrán calc-alkaline chain of plutons (see Appendix 4 for a further Jurassic K-Ar date for the Azafrán Complex). This hypothesis is based on the apparent lack of pre (skarn) tectono-metamorphic history. However, in many cases, it could be suggested that the skarn metamorphism would obliterate the previous tectono-metamorphic fingerprints.

Nor has it been demonstrated that the skarns are related to the Azafrán calc-alkaline chain. This relationship is only indicated by their close proximity and by the abundance of calcite-biotite-sulphide veins in the plutonic rocks. The relationship of the skarns and the late mylonite belts is also unknown; although certain blocks exhibit local gneissose zones.

Clearly much work is required to formulate the geological history of the sector particularly with respect to the relationships between the gneiss/schist sequence, the skarn protoliths, the plutonic and metaplutonic rocks, and the mylonites. The presence of ophiolitic blocks in the Río Mulatos could also be significant in any attempt to correlate the skarn protolith with Paleozoic or Mesozoic rocks of the eastern lowland platform. The metamorphic/metasomatic phase history of this skarn formation and its relationship to gold mineralization is a complex study in itself.

4.1.4 On the possibility of correlating the Llanganates and Nambija skarn gold belts

The Nambija skarns (Appendix 3) are pale rocks dominated by grandite garnet and related to a calc-alkaline plutonic complex (Zamora 'batholith'), provisionally dated as Jurassic in age (Appendix 4). The skarn protolith age is not known, but if the Jurassic age for the complex is confirmed, then the Cretaceous Napo limestone can be eliminated as a candidate. Float magnetite blocks have been noted in rivers draining the Zamora batholith (Ing. L. Torres, pers. comm.).

The preliminary dating shows the Azafrán and Zamora calc-alkaline complexes to be of similar age (Appendix 3). The Azafrán chain has been extended south along a strike to Abanico (Map 1). Further south a river block of pale skarn (clinopyroxene-amphibole-garnet) was collected east of the Baños front on the Paute-Méndez geotraverse.

These points indicate the possibility that the skarns of Llanganates and Nambija relate to a common calc-alkaline plutonic chain and a common skarn protolith. Absence of skarn rocks over certain sectors (e.g. Guamote-Macas, Papallacta-Baeza, Ibarra-La Bonita) could be accounted for by the subsequent tectonic emplacement of skarn rocks, at differing levels along the Cordillera Real.

4.2 The Baños Front-related Ag-Cu-Zn-Pb belt

The line of the Baños front has been traced on geological grounds; though this important fundamental tectonic break in the Cordillera Real has yet to be interpreted satisfactorily. It is remarkable how this line relates to pre-existing and new Ag-Cu-Zn-Pb hydrothermal polymetallic vein-type deposits along the ca. 200 km of strike length so far delimited. From north to south these are as follows:

4.2.1 Baños area

There is an occurrence of Cu-Zn deposits in the schists and gneisses of the Central belt near Agoyán, about 3 km east of the Baños front. Old silver workings are also reported south of Baños at Tungurahua (National History Archives, 7/8/1766).

4.2.2 Atillo-Guarumales

Over this sector A. Hirtz (pers. comm) reports polymetallic mineralization in the north close to the Baños front; whilst along the front at Guarumales the Project noted polymetallic mineralization within a region of geochemical Pb-Mo-Zn anomalies (Bristow et al., 1980). To the west of this sector lies the old silver mine of Pilzhum.

4.2.3 Condorazo-Cubillín-Alao

There are numerous old silver mines, with associated Zn-Pb-Cu mineralization, which straddle the Baños front from Tungurahua south to the Licto-Huamboya (Alao) traverse (Navarro 1986, Vol. II). These occur in both the Cenozoic volcanics of Altar and in the underlying metamorphic rocks (A. Hirtz, pers. comm). Small mineralized quartz veins were noted on both sides of the Baños front over the Alao-Huamboya watershed; i.e. in the blue quartz metagranite to the east of the front and in the Alao greenstones to the west. Polymetallic mineralization in the Alao greenstones continues westwards to the Alao region towards the Peltetec ophiolite (see 4.3) (A. Hirtz, pers. comm).

4.2.4 Sigsig-Gima

In the region of Peggy Mine (Sigsig), straddling the Baños front, there are Ag-Cu-Zn-Pb veins (Entwistle, 1982), and Ag indices further along the strike to the south at Gima (Goossens, 1972). West of the Baños front lies the important San Bartolomé polymetallic mine within diorites and Cenozoic pyroclastics (Goossens, 1974) overlying the Alao greenstones.

4.2.5 Discussion

The tracing of fundamental lithological divisions and tectonic fronts appears to present some form of control on the polymetallic mineralization from Baños to Sigsig. The mineralization is noted close to the line of the Baños front and also westwards (Alao greenstones) and to a lesser extent eastwards (Central belt), either in the metamorphic rocks or within overlying Cenozoic sequences. If the Alao greenstones do represent an accreted island arc, then the occurrence of Ag-Cu-Zn-Pb mineralization within them and along the Baños front ?collision zone could be interpreted as hydrothermal remobilisation of primary volcanogenic sulphides of primitive or Kuroko type (Edwards and Atkinson, 1986). In both cases the mineral concentrations should relate to local island arc volcanic centres.

4.3 The Peltetec Ophiolite Belt

This complex belt of serpentinites, gabbros, spillitic lavas, cherts, fine-grained oceanic sediments, and fore-arc deposits is characterised at Peltetec and Huarguallá by visible copper and zinc mineralization and geochemical anomalies of nickel and chromium. Detailed prospecting of the Peltetec region by A. Hirtz (pers. comm.) shows maximum rock analyses of chromium (0.11 %), antimony (0.23 %), zinc (0.63 %) and arsenic (0.12%), with gold values increasing towards the Peltetec region.

Whilst the serpentinites are narrow and the regional tectonics complex, the presence of ophiolitic-type rocks and characteristic geochemical anomalies (e.g. chromium and nickel) indicates the need to trace this belt further afield and prospect for mineralisation of ophiolite type.

5. CONCLUSIONS AND FUTURE WORK

The first year's studies have provided a provisional geological and plate-tectonic framework for the Cordillera Real, and defined three new mineral belts, the geological settings of which can be provisionally related to this framework. Thus, it can be said that the aims of the Project are being fulfilled.

Many problems remain and it is expected that the geochronological programme and further geotraverses will define more clearly the geological history of the area, the nature and extensions of the mineral belts, and determine yet undiscovered mineral zones. Regional studies will then be progressively superseded by more detailed geological/mineral prospection investigations. A geotraverse across the El Oro metamorphic belt is essential in terms of regional correlation and the understanding of the Huancabamba Deflection.

On the metallic mineral side, the investigation of the Llanganates skarn gold belt is in its infancy in terms of outcrop locations and studies of skarn mineralogy and geological setting. However, since this belt may represent the major source of alluvial gold as well as an important primary gold deposit, further immediate studies are warranted.

Should funding be made available, the Project should follow up the gold compositional studies (Appendix 3) by carrying out detailed studies over the Zamora batholith and skarns, the alluvial gold of the lowlands, and the Llanganates skarns, in order to determine the primary gold geneses and the existence or not of the Llanganates-Nambija correlation (4.1.4).

The Peltetec ophiolite is geologically, and possibly economically, significant and warrants more detailed economic studies and regional investigations to determine its southward extension. Other serpentinites found as loose blocks over the Central belt (including recently-confirmed serpentinites in the Río Mulatos) should also be investigated.

Most of the mineral occurrences of the Baños front-related polymetallic belt and those in the adjacent Alao greenstones are previously known and are being re-investigated by the private sector.

On the industrial minerals side, it is pertinent to note the inventory already accumulated by the Project, which includes new deposits of asbestos and phosphate rock.

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APPENDIX 1

Analyses and data of mineralised samples

Table 1. Analyses of mineralised samples

ZONE	SAMPLE CODE	P ₂ O ₅ (%)	Cr (ppm)	Mn (ppm)	FeO+Fe ₂ O ₃ (%)	Co (ppm)	Ni (ppm)	Cu (ppm)	Zn (ppm)	Mo (ppm)	Ag (ppm)	W (ppm)	Au (ppm)	Pb (ppm)
AMBUQUÍ	CR-RB-86-167-D					34	742	116	236					
PAPALLACTA	CR-RB-86-25-D													
RÍO MULATOS	CR-RB-86-137		62	2100	19.25	366	62	273	112	nd	19	1700	10.0 11.1	192
	CR-RB-86-140-B		87	491	29.05	108	143	61	587	nd	10	413	3.0 2.4	238
	CR-RB-86-145-C		38	1800	39.08	95	73	34	309	35	12	808	4.4 3.6	225
	CR-RB-86-148		20	1500	7.88	156	54	243	453	53	8	533	0.9 0.7	139
	CR-RB-86-149		43	1400	13.64	223	54	249	441	40	22	870	15.2 13.8	179
	CR-RB-86-151		26	788	6.42	21	43	21	450	nd	11	nd	2.6	93
	CR-RB-86-159-A													
PELTETEC	CR-RB-86-59-G		277			53	155	22	369					131
	CR-RB-86-60-C		106			113	66	18	89					178
	CR-RB-86-61-B		712			49	238	11000	1700					416
	CR-RB-86-61-D		1600			23	197	49300	477		18	110	0.2	238
	CR-RB-86-127		215			42		393	1388		8	87	nd	120
HUARGUALLÁ	CR-RB-86-87-K		570			169		15200	227		14	81	1.0	124
	CR-RB-86-126-B			859	6.15	46	131	45	174				nd	127
	CR-RB-86-126-D			870	7.09	47	121	102	192				nd	118
RÍO CEBADAS	CR-RB-86-83			685	2.75	55	38	34	146					102
	CR-RB-86-86			1100	24.32	62	55	33	237					137
RÍO UPANO	CR-RB-86-105		40			411		252	193		8	80	0.2	155
	CR-RB-86-117-C			113	1.00	57	38	21	216				0.1	150
	CR-RB-86-121-B		35			62		273	199		6	341	0.2	95
	CR-RB-86-122-A			84	1.00	36	72	54	76				0.2	60
	CR-RB-86-122-B			87	1.30	24	88	46	113				0.1	99
	CR-RB-86-122-C			212	4.45	33	59	35	233				nd	156
	CR-RB-86-122-D			276	2.85	47	74	57	159				nd	124
GUARUMALES	CR-FV-86-156						103		231	nd	5		0.08	390

Analyses by the INEMIN laboratory; nd = not detected

DATA ON THE ANALYSED SAMPLES

CR-RB-86-167D: Panamerican highway near Ambuquí (8342-99495), Ibarra-La Bonita geotraverse, quartz vein (10cm) with weathering red mineral in graphitic phyllites and quartzites.

CR-RB-86-25D: Papallacta-Baeza road. 7km from Papallacta (8233-99604), stream float block, thin section shows apatite-bearing tonalitic rock.

CR-RB-86-137: Float block, Río Mulatos, black medium-grained skarn: garnet (40%), quartz and chlorite.

CR-RB-86-140B: Loose block, Río Mulatos, ferruginous black phyllite with sulphides.

CR-RB-86-145C: Float block, Río Mulatos (8883-98131), pale skarn with carbonate and epidote, with veins and dissemination of magnetite.

CR-RB-86-148: Float block, Río Mulatos (8855-98140), black schist almost pure biotite with sulphides.

CR-RB-86-149: Float block, Río Mulatos (8845-98147), black fine grained skarn, ?amphibole-epidote-sulphides.

CR-RB-86-151: Float block, Río Mulatos, black skarn, garnet-epidote-amphibole-magnetite.

CR-RB-86-159A: Río Mulatos (8836-98190), in situ band of phosphatic limestone (50 cm) in red calcilutites and black shales.

CR-RB-86-59G: Pungalá-Alao road (7716-97946), non-mineralised serpentinite from the Peltetec ophiolite.

CR-RB-86-60C: Pungalá-Alao road (7717-97946), block of quartz-epidote-asbestos vein (Peltetec ophiolite).

CR-RB-86-126A: Gossan zone above CR-RB-86-61D.

CR-RB-86-61D: Maguazo bridge-Peltetec road (7735-97949), altered mineralised zone in black phyllites, near Peltetec ophiolite.

CR-RB-86-127: Same location, Zn mineralised vein.

CR-RB-86-87K: Aqueduct, Huarguallá Valley (7713-97923), serpentinite with Cu mineralization, Peltetec ophiolite extension.

CR-RB-86-126B: Same aqueduct (7718-97922), purple phyllite of the ophiolite zone.

CR-RB-86-126D: Same location, fine, silicified purple and green metasediments.

CR-RB-86-83: Guamote-Atillo road (7640-97694), black fine silicified metasediment, part of ophiolite sequence.

CR-RB-86-86: Float block from Río Tingo (7675-97704), black slate with sulphides.

CR-RB-86-105: Macas-Atillo road (7987-97555), “metagraywacke” with Cu mineralization.

CR-RB-86-117C: Macas-Atillo road (8090-97515), ‘sooty’ black meta-arenite.

CR-RB-86-121B: Macas-Atillo road, near Río Colimbo (8113-97494), siliceous black meta-lutite with sulphides.

CR-RB-86-122A: Macas-Atillo road, float block in Río Colimbo (8113-97494), siliceous black meta-lutite.

CR-RB-86-122B: Same location, black slate.

CR-RB-86-122C: Same location, black slate.

CR-RB-86-122D: Same location, black meta-siltstone with sulphides.

CR-FV-86-156: 2m concordant massive sulphide band in greenschists, Guarumales (7780-97154)

APPENDIX 2

Geochemical analyses of stream sediment samples from the
geotraverses

English translation by Stalyn Paucar (2026)

INSTITUTO ECUATORIANO DE MINERÍA
DEPARTAMENTO DE LABORATORIOS
CHEMICAL ANALYSIS REPORT

LAB N°: 3550 DELIVERY: Ing. Iván Endara DATE: 13-08-86
N° of SAMPLES: Nineteen Jefe de Laboratorios
REQUESTED BY: Ing. F. Viteri RECEPTION: Ing. W. Santamaría DATE: 13-08-86
PROJECT: Cordillera Real Director de investigación geológica
ORIGIN: Zamora – Zamora; Azuay – Saraguro; Loja – Loja; Saraguro-Loja, Catamayo-Loja-Zamora

DETERMINATIONS

SAMPLE CODE	Zn (ppm)	Pb (ppm)	Co (ppm)	Cu (ppm)	Ni (ppm)
A0001	152	124	30	26	39
A0002	131	194	30	24	57
A0003	98	115	20	12	32
A0004	79	160	34	10	60
A0005	123	160	51	21	60
A0006	100	228	59	22	88
A0007	219	148	42	27	44
A0008	90	102	24	21	36
A0009	95	157	69	30	48
A0010	105	106	16	26	23
A0011	65	96	28	12	47
A0012	93	93	24	23	34
A0013	100	140	44	32	46
A0014	157	151	45	42	59
A0015	101	124	35	23	36
A0016	95	131	33	29	57
A0017	92	102	33	27	48
A0018	56	110	18	10	12
A0019	70	115	20	15	22

ASSAYED BY: Determinaciones Analíticas

SUSANA SALVADOR A.
Jefe de Determinaciones Analíticas

INSTITUTO ECUATORIANO DE MINERÍA
DEPARTAMENTO DE LABORATORIOS
CHEMICAL ANALYSIS REPORT

LAB N°: 3576 DELIVERY: Ing. Iván Endara DATE: 1987
N° of SAMPLES: Nineteen Jefe de Laboratorios
REQUESTED BY: Ing. F. Viteri RECEPTION: Ing. W. Santamaría DATE: 1987
PROJECT: Cordillera Real Director de investigación geológica
ORIGIN: Zamora, Azuay, Loja; Zamora, Saraguro, Loja; Saraguro-Loja, Catamayo-Loja-Zamora

DETERMINATIONS

SAMPLE CODE	As (ppm)	Cr (ppm)
A0001	12	41
A0002	6	80
A0003	6	43
A0004	5	206
A0005	5	140
A0006	5	422
A0007	5	82
A0008	5	77
A0009	2	60
A0010	4	36
A0011	5	108
A0012	4	60
A0013	5	98
A0014	5	137
A0015	4	84
A0016	4	125
A0017	7	100
A0018	5	43
A0019	4	55

ASSAYED BY: Determinaciones Analíticas

SUSANA SALVADOR A.
Jefe de Determinaciones Analíticas

NOTE: The samples correspond to the LAB 3550

INSTITUTO ECUATORIANO DE MINERÍA

DEPARTAMENTO DE LABORATORIOS

CHEMICAL ANALYSIS REPORT

LAB N°: 3575

DELIVERY: Ing. Iván Endara

DATE: 26-09-86

N° of SAMPLES: Nineteen

Jefe de Laboratorios

REQUESTED BY: Ing. F. Viteri

RECEPTION: Ing. W. Santamaría

DATE: 29-09-86

PROJECT: Cordillera Real

Director de investigación geológica

ORIGIN: Azuay different zones; Limón-Gualaceo

DETERMINATIONS

SAMPLE CODE	Zn (ppm)	Pb (ppm)	Co (ppm)	Cu (ppm)	Ni (ppm)	Cr (ppm)
A0020	230	134	29	27	47	84
A0021	70	104	30	47	73	116
A0022	111	58	14	32	31	30
A0023	56	109	22	21	42	58
A0024	81	83	24	30	39	48
A0025	76	124	26	20	41	63
A0026	63	53	16	18	32	32
A0027	88	134	32	29	53	70
A0028	51	30	12	15	19	16
A0029	84	112	28	22	35	51
A0030	43	33	10	30	15	15
A0031	45	43	9	17	18	25
A0032	58	51	15	17	28	37
A0033	32	8	4	20	8	5
A0034	31	9	6	8	12	10
A0035	56	27	10	16	19	25
A0036	57	37	11	16	20	37
A0037	112	125	49	61	39	28
A0038	247	98	28	61	61	45

ASSAYED BY: Determinaciones Analíticas

MARIANA LÓPEZ

Jefe de Determinaciones Analíticas

INSTITUTO ECUATORIANO DE MINERÍA
DEPARTAMENTO DE LABORATORIOS
CHEMICAL ANALYSIS REPORT

LAB N°: 3595	DELIVERY: Ing. Iván Endara	DATE:
N° of SAMPLES: Thirty-eight	Jefe de Laboratorios	
REQUESTED BY: Ing. F. Viteri	RECEPTION: Ing. W. Santamaría	DATE:
PROJECT: Cordillera Real	Director de investigación geológica	
ORIGIN: Cañar-Azuay-Morona Santiago; Paute-Méndez		

DETERMINATIONS

SAMPLE CODE	Zn (ppm)	Pb (ppm)	Co (ppm)	Mn (ppm)	Cu (ppm)	Ni (ppm)	Cr (ppm)
A0039	310	103	28	573	97	97	68
A0040	127	84	29	582	32	44	29
A0041	129	97	33	781	71	85	111
A0042	137	75	18	609	33	29	21
A0043	166	105	24	720	62	47	34
A0044	146	98	29	740	56	45	24
A0045	216	104	24	863	38	34	21
A0046	121	85	20	509	32	30	19
A0047	108	100	27	679	46	37	24
A0048	122	94	26	706	41	39	33
A0049	75	71	19	547	28	24	12
A0050	2300	74	17	577	50	22	15
A0051	270	91	20	936	50	52	26
A0052	635	101	27	518	98	147	112
A0053	104	94	30	872	96	96	35
A0054	109	96	31	786	111	48	50
A0055	100	85	23	723	37	40	81
A0056	66	77	20	607	29	32	76
A0057	124	113	36	711	60	78	169
A0058	81	45	9	216	21	15	17
A0059	143	78	17	361	45	31	29
A0060	144	59	16	519	29	18	12
A0061	78	84	27	592	35	65	79
A0062	98	77	17	398	51	39	44
A0063	91	79	16	387	48	35	34
A0064	228	90	26	699	76	40	39
A0065	100	101	32	692	66	53	65
A0066	232	105	26	1000	181	28	15
A0067	156	83	21	745	74	24	13
A0068	155	105	23	1000	67	29	20
A0069	245	117	26	791	62	66	38
A0070	161	116	23	675	52	41	45
A0071	329	102	13	194	43	65	55
A0072	317	116	17	359	44	70	59
A0073	446	135	20	233	60	78	75
A0074	96	92	16	289	15	28	35
A0075	156	88	15	225	26	41	46
A0076	131	92	29	631	38	39	34

ASSAYED BY: Determinaciones Analíticas
SUSANA SALVADOR A.
Jefe de Determinaciones Analíticas

NOTE: As results will be delivered at a later date.
(See Appendix 2, 2nd Annual Report, 1988).

INSTITUTO ECUATORIANO DE MINERÍA

DEPARTAMENTO DE LABORATORIOS

CHEMICAL ANALYSIS REPORT

LAB N°: 3618

DELIVERY: Ing. Iván Endara

DATE: 13-02-87

N° of SAMPLES: Twenty

Jefe de Laboratorios

REQUESTED BY: Ing. F. Viteri

RECEPTION: Ing. W. Santamaría

DATE: 17-02-87

PROJECT: Cordillera Real

Director de investigación geológica

ORIGIN: Loja-Zamora Chinchipe; Loja-Zumba

DETERMINATIONS

SAMPLE CODE	As (ppm)	Zn (ppm)	Pb (ppm)	Co (ppm)	Mn (ppm)	Cu (ppm)	Ni (ppm)	Cr (ppm)
A0077	30	78	121	23	546	21	423	141
A0078	34	70	93	20	450	15	303	101
A0079	44	73	91	18	371	12	784	181
A0080	30	32	35	10	175	5	1000	204
A0081	50	79	80	17	301	14	880	191
A0082	50	89	96	21	549	19	1100	256
A0083	18	102	107	25	774	24	735	211
A0084	38	102	125	42	1300	35	561	202
A0085	32	92	93	24	545	23	235	82
A0086	18	98	101	21	569	22	567	155
A0087	20	133	221	48	968	25	399	136
A0088	26	106	105	23	655	21	588	156
A0089	22	86	114	21	546	17	615	166
A0090	50	101	128	21	508	11	597	158
A0091	40	109	101	20	464	19	485	119
A0092	30	86	88	16	414	17	397	103
A0093	36	80	69	18	436	18	488	122
A0094	24	94	133	24	451	18	245	89
A0095	20	82	103	29	686	23	263	122
A0096	26	102	115	33	846	34	487	165

ASSAYED BY: Determinaciones Analíticas

SUSANA SALVADOR A.

Jefe de Determinaciones Analíticas

INSTITUTO ECUATORIANO DE MINERÍA
DEPARTAMENTO DE LABORATORIOS
CHEMICAL ANALYSIS REPORT

LAB N°: 3551 DELIVERY: Ing. Iván Endara DATE: 13-08-86
N° of SAMPLES: Nineteen Jefe de Laboratorios
REQUESTED BY: Dr. M. Litherland RECEPTION: Ing. W. Santamaría DATE: 13-08-86
PROJECT: Cordillera Real Director de investigación geológica
ORIGIN: Baños-Puyo (001-013); Licto-Huamboya (014-019)

DETERMINATIONS

SAMPLE CODE	Zn (ppm)	Pb (ppm)	Co (ppm)	Cu (ppm)	Ni (ppm)
CR-86-B-001	218	160	85	47	106
CR-86-B-002	151	175	62	51	103
CR-86-B-003	134	139	50	44	94
CR-86-B-004	83	147	54	42	93
CR-86-B-005	110	162	48	53	58
CR-86-B-006	69	154	38	52	48
CR-86-B-007	74	148	33	63	32
CR-86-B-008	159	169	65	53	97
CR-86-B-009	77	125	32	52	33
CR-86-B-010	96	148	34	70	35
CR-86-B-011	80	118	23	49	26
CR-86-B-012	105	119	22	47	32
CR-86-B-013	145	144	29	33	31
CR-86-B-014	111	141	41	56	74
CR-86-B-015	112	137	42	72	69
CR-86-B-016	110	142	46	55	58
CR-86-B-017	112	141	49	84	71
CR-86-B-018	90	124	80	76	801
CR-86-B-019	NO SAMPLE				

ASSAYED BY: Determinaciones Analíticas

SUSANA SALVADOR A.
Jefe de Determinaciones Analíticas

INSTITUTO ECUATORIANO DE MINERÍA
DEPARTAMENTO DE LABORATORIOS
CHEMICAL ANALYSIS REPORT

LAB N°: 3577 DELIVERY: Ing. Iván Endara DATE: 20-03-87
N° of SAMPLES: Nineteen Jefe de Laboratorios
REQUESTED BY: Dr. M. Litherland RECEPTION: Ing. W. Santamaría DATE:
PROJECT: Cordillera Real Director de investigación geológica
ORIGIN: Baños-Puyo (001-013); Licto-Huamboya (014-019)

DETERMINATIONS

SAMPLE CODE	As (ppm)	Cr (ppm)
CR-86-B-001	28	234
CR-86-B-002	24	214
CR-86-B-003	42	202
CR-86-B-004	42	199
CR-86-B-005	34	105
CR-86-B-006	46	95
CR-86-B-007	30	55
CR-86-B-008	54	197
CR-86-B-009	34	79
CR-86-B-010	42	47
CR-86-B-011	26	52
CR-86-B-012	70	58
CR-86-B-013	28	44
CR-86-B-014	38	126
CR-86-B-015	38	120
CR-86-B-016	64	138
CR-86-B-017	34	182
CR-86-B-018	38	651
CR-86-B-019	NO SAMPLE	

ASSAYED BY: Determinaciones Analíticas

SUSANA SALVADOR A.
Jefe de Determinaciones Analíticas

NOTE: These are samples from LAB 3551

INSTITUTO ECUATORIANO DE MINERÍA
DEPARTAMENTO DE LABORATORIOS
CHEMICAL ANALYSIS REPORT

LAB N°: 3583 DELIVERY: Ing. Iván Endara DATE:
N° of SAMPLES: Seventeen Jefe de Laboratorios
REQUESTED BY: Dr. M. Litherland RECEPTION: Ing. W. Santamaría DATE:
PROJECT: Cordillera Real Director de investigación geológica
ORIGIN: Chimborazo and Morona Santiago; Guamote-Macas

DETERMINATIONS

SAMPLE CODE	Zn (ppm)	Pb (ppm)	Co (ppm)	Cu (ppm)	Cr (ppm)
CR-RB-86-B-020	92	117	25	58	63
CR-RB-86-B-021	117	115	36	69	103
CR-RB-86-B-022	80	107	29	76	65
CR-RB-86-B-023	94	111	32	65	93
CR-RB-86-B-024	84	107	30	70	71
CR-RB-86-B-025	71	106	28	66	62
CR-RB-86-B-026	120	122	35	85	87
CR-RB-86-B-027	114	139	40	81	121
CR-RB-86-B-028	136	133	38	79	80
CR-RB-86-B-029	139	67	16	30	46
CR-RB-86-B-030	135	144	39	65	50
CR-RB-86-B-031	101	123	32	89	40
CR-RB-86-B-032	85	82	20	53	53
CR-RB-86-B-033	339	114	33	125	45
CR-RB-86-B-034	131	107	24	52	24
CR-RB-86-B-035	114	88	21	48	47
CR-RB-86-B-036	138	90	22	54	45

ASSAYED BY: Determinaciones Analíticas

SUSANA SALVADOR A.
Jefe de Determinaciones Analíticas

NOTE: As, W, and Ni results will be reported at a later date

INSTITUTO ECUATORIANO DE MINERÍA
DEPARTAMENTO DE LABORATORIOS
CHEMICAL ANALYSIS REPORT

LAB N°: 3583 DELIVERY: Ing. Iván Endara DATE: 09-12-86
N° of SAMPLES: Seventeen Jefe de Laboratorios
REQUESTED BY: Dr. M. Litherland RECEPTION: Ing. W. Santamaría DATE: 10-12-86
PROJECT: Cordillera Real Director de investigación geológica
ORIGIN: Chimborazo and Morona Santiago; Guamote-Macas

DETERMINATIONS

SAMPLE CODE	As (ppm)	W (ppm)	Ni (ppm)
CR-RB-86-B-020	29	36	60
CR-RB-86-B-021	17	59	111
CR-RB-86-B-022	25	22	83
CR-RB-86-B-023	15	Nd	104
CR-RB-86-B-024	17	Nd	89
CR-RB-86-B-025	19	12	76
CR-RB-86-B-026	38	Nd	100
CR-RB-86-B-027	29	14	112
CR-RB-86-B-028	23	35	97
CR-RB-86-B-029	23	7	51
CR-RB-86-B-030	96	7	106
CR-RB-86-B-031	48	35	69
CR-RB-86-B-032	29	7	47
CR-RB-86-B-033	126	11	51
CR-RB-86-B-034	48	9	40
CR-RB-86-B-035	27	4	55
CR-RB-86-B-036	33	46	51

Nd = Not detectable, less than 7 ppm W

ASSAYED BY: Determinaciones Analíticas

SUSANA SALVADOR A.
Jefe de Determinaciones Analíticas

INSTITUTO ECUATORIANO DE MINERÍA
DEPARTAMENTO DE LABORATORIOS
CHEMICAL ANALYSIS REPORT

LAB N°: 3613 DELIVERY: Ing. Iván Endara DATE: 13-02-87
N° of SAMPLES: Twelve Jefe de Laboratorios
REQUESTED BY: Dr. M. Litherland RECEPTION: Ing. W. Santamaría DATE: 17-02-87
PROJECT: Cordillera Real Director de investigación geológica
ORIGIN: Napo; Salcedo – Tena (Río Mulatos)

DETERMINATIONS

SAMPLE CODE	Zn (ppm)	Pb (ppm)	Co (ppm)	Cu (ppm)	Cr (ppm)	As (ppm)	Ni (ppm)
CR-RB-86-B-037	46	51	14	37	28	24	29
CR-RB-86-B-038	47	98	22	34	41	46	32
CR-RB-86-B-039	64	52	18	79	21	44	30
CR-RB-86-B-040	72	141	25	63	30	40	36
CR-RB-86-B-041	70	133	23	68	35	22	37
CR-RB-86-B-042	68	74	18	107	16	38	25
CR-RB-86-B-043	86	184	39	159	30	58	40
CR-RB-86-B-044	76	72	20	112	6	22	14
CR-RB-86-B-045	175	154	23	42	59	28	66
CR-RB-86-B-046	130	101	20	83	36	52	52
CR-RB-86-B-047	77	114	29	69	40	30	61
CR-RB-86-B-048	101	133	23	53	39	24	48

ASSAYED BY: Determinaciones Analíticas

SUSANA SALVADOR A.
Jefe de Determinaciones Analíticas

INSTITUTO ECUATORIANO DE MINERÍA
DEPARTAMENTO DE LABORATORIOS
CHEMICAL ANALYSIS REPORT

LAB N°: 3613 DELIVERY: Ing. Iván Endara DATE: 86-12-02
N° of SAMPLES: Twelve Jefe de Laboratorios
REQUESTED BY: Dr. M. Litherland RECEPTION: Ing. W. Santamaría DATE: 86-12-
PROJECT: Cordillera Real Director de investigación geológica
ORIGIN: Napo; Salcedo – Tena (Río Mulatos)

DETERMINATIONS

SAMPLE CODE	Zn (ppm)	Pb (ppm)	Co (ppm)	Cu (ppm)	Ni (ppm)	Cr (ppm)
CR-RB-86-B-037	97	97	22	44	62	53
CR-RB-86-B-038	59	78	19	30	46	49
CR-RB-86-B-039	108	100	25	77	56	54
CR-RB-86-B-040	104	114	24	67	38	32
CR-RB-86-B-041	101	135	22	71	46	41
CR-RB-86-B-042	123	135	27	117	42	32
CR-RB-86-B-043	98	144	34	157	58	37
CR-RB-86-B-044	101	112	26	115	39	29
CR-RB-86-B-045	200	135	24	49	70	63
CR-RB-86-B-046	233	144	32	118	62	51
CR-RB-86-B-047	184	132	32	108	59	44
CR-RB-86-B-048	160	129	27	74	44	45

ASSAYED BY: Determinaciones Analíticas

SUSANA SALVADOR A.
Jefe de Determinaciones Analíticas

NOTE: As results will be reported at a later date.

INSTITUTO ECUATORIANO DE MINERÍA
DEPARTAMENTO DE LABORATORIOS
CHEMICAL ANALYSIS REPORT

LAB N°: 3635 DELIVERY: Ing. Iván Endara DATE: 1987
N° of SAMPLES: Fifteen Jefe de Laboratorios
REQUESTED BY: Dr. M. Litherland RECEPTION: Ing. W. Santamaría DATE: 1987
PROJECT: Cordillera Real Director de investigación geológica
ORIGIN: Imbabura and Napo; Ambuquí – La Bonita

DETERMINATIONS

SAMPLE CODE	Zn (ppm)	Co (ppm)	Cu (ppm)	Ni (ppm)	Cr (ppm)
CR-RB-86-B-049	104	40	44	59	84
CR-RB-86-B-050	102	37	42	59	102
CR-RB-86-B-051	113	40	42	56	105
CR-RB-86-B-052	80	24	27	46	70
CR-RB-86-B-053	61	18	23	41	56
CR-RB-86-B-054	186	48	18	52	69
CR-RB-86-B-055	88	24	15	25	28
CR-RB-86-B-056	82	24	19	28	33
CR-RB-86-B-057	154	46	32	56	86
CR-RB-86-B-058	96	36	23	45	66
CR-RB-86-B-059	127	34	56	50	71
CR-RB-86-B-060	106	27	40	43	58
CR-RB-86-B-061	107	36	27	60	101
CR-RB-86-B-062	93	35	28	38	52
CR-RB-86-B-063	81	22	21	27	31

ASSAYED BY: Determinaciones Analíticas

SUSANA SALVADOR A.
Jefe de Determinaciones Analíticas

NOTE: As and Mo results will be reported at a later date.

INSTITUTO ECUATORIANO DE MINERÍA
DEPARTAMENTO DE LABORATORIOS
CHEMICAL ANALYSIS REPORT

LAB N°: 3635 DELIVERY: Ing. Iván Endara DATE: 22-05-87
N° of SAMPLES: Fifteen Jefe de Laboratorios
REQUESTED BY: Dr. M. Litherland RECEPTION: Ing. W. Santamaría DATE: 25-05-87
PROJECT: Cordillera Real Director de investigación geológica
ORIGIN: Imbabura and Napo; Ambuquí – La Bonita

DETERMINATIONS

SAMPLE CODE	Mo (ppm)	As (ppm)
CR-RB-86-B-049	Nd	22
CR-RB-86-B-050	Nd	16
CR-RB-86-B-051	Nd	28
CR-RB-86-B-052	31	34
CR-RB-86-B-053	31	28
CR-RB-86-B-054	Nd	18
CR-RB-86-B-055	Nd	25
CR-RB-86-B-056	Nd	36
CR-RB-86-B-057	Nd	34
CR-RB-86-B-058	35	48
CR-RB-86-B-059	36	32
CR-RB-86-B-060	Nd	46
CR-RB-86-B-061	Nd	84
CR-RB-86-B-062	Nd	42
CR-RB-86-B-063	34	40

Nd = Not detectable, less than 30 ppm Mo

ASSAYED BY: Determinaciones Analíticas

SUSANA SALVADOR A.
Jefe de Determinaciones Analíticas

APPENDIX 3

Mineralogy Petrology Research Group

Report No. 87/3

A pilot examination of alluvial and in situ
gold and platinum from Ecuador

B. Beddoe-Stephens

February 1987

Mineralogy and Petrology Research Group

Geochemistry Directorate

British Geological Survey

Murchison House

West Mains Road

Edinburgh EH9 3LA

A pilot examination of alluvial and in situ gold and platinum from Ecuador

Mineralogy & Petrology Report No. 87/3

B. Beddoe – Stephens. February 1987.

1. Introduction

This report details an examination of a suite of gold samples from Ecuador. They were submitted by Dr. J. A. Aspden (Overseas Directorate, BGS) for a pilot study prior to a possibly more substantial and systematic examination of alluvial and in situ gold as part of the Ecuador Cordillera Real project. The samples and localities are listed below (Table 1A). The approach has predominantly been a chemical examination, all the grains being analysed by electron-probe in order to determine whether any systematic variation exists that can be related to differing styles of mineralisation in different localities. Comparison is also attempted utilizing data accumulated in the past from elsewhere in Latin America and Indonesia, where similar studies have been undertaken.

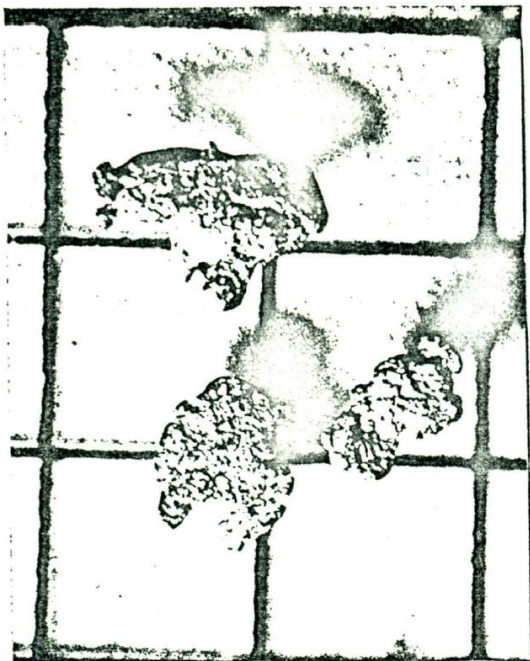
2. Details of the samples and sample preparation

The localities and a brief description of the samples as submitted are given in Table 1A and B. JACR 1-16 are alluvial gold grains, JACR-17 comprises alluvial platinum grains, and JACR 18-19 are rock samples containing visible native gold.

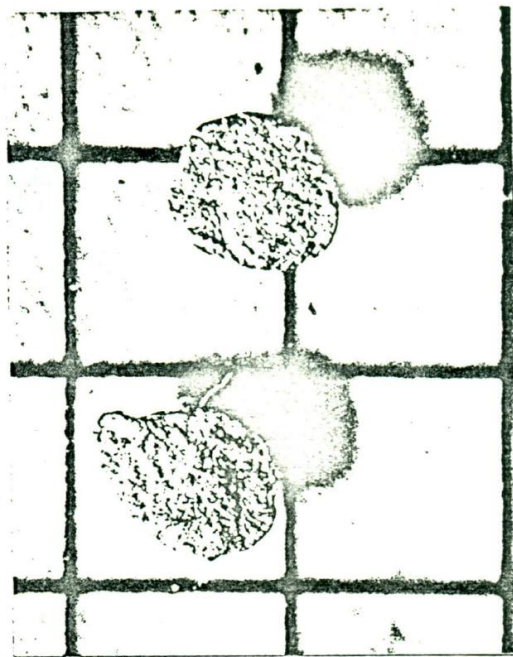
The alluvial grains were mounted in araldite, either on glass slides or in blocks, ground down and polished to allow accurate microprobe analysis and optical examination in reflected light. Polished thin sections of JACR-19 skarn were also prepared, and in addition to analysis of the gold the silicate gangue minerals were analysed by probe. Sample JACR-18 was not suitable for polished section preparation due to the fine grain size and friable nature of the rock.

3. Results

3.1 Alluvial gold. The alluvial golds all show characteristic morphologies derived from mechanical transport in the fluvial regime. In particular most grains are flattened platelets that show evidence of pounding, folding and tearing. Grain margins tend to be rounded and there is no evidence of crystalline form (Fig. 1). Sample JACR-3 is an exception, the 5 grains being larger than average equidimensional and contain a large amount of quartz intergrown with the gold. Figure 2 shows that this intergrowth is primary with the quartz displaying good euhedral forms adjacent to interstitial gold. This particular sample is probably quite close to source and represents fragments of vein material. Ultimately, mechanical working will separate the brittle quartz from the malleable gold, the latter then readily being pummelled into its characteristic plate-like form.



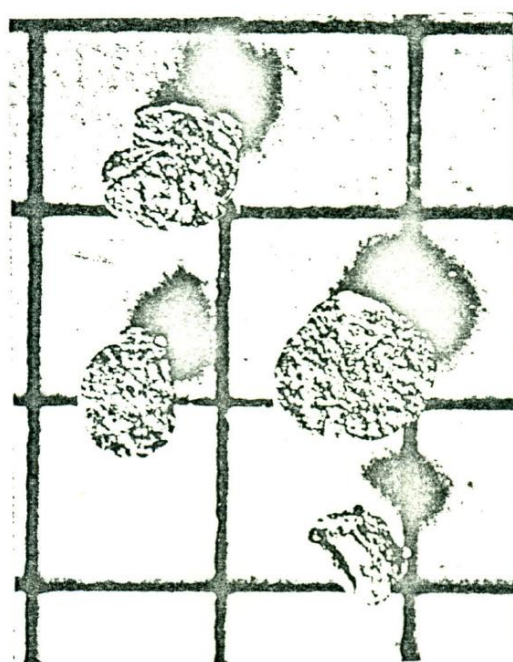
JACR-5



JACR-8

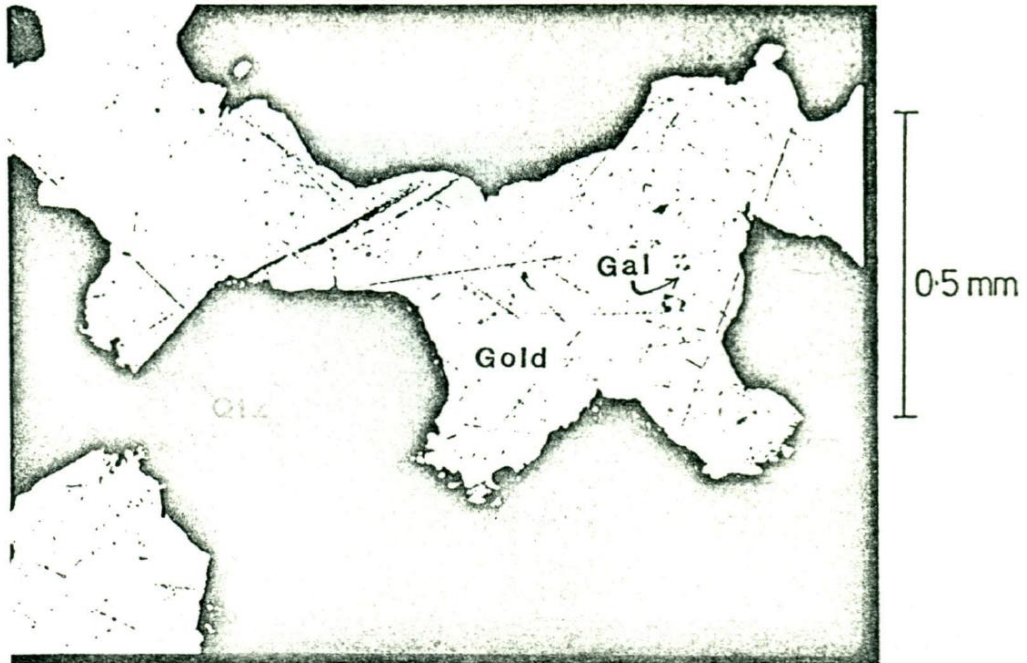


JACR-12



JACR-16

Figure 1. Gold flakes. Grid is 2mm square



A) JACR-3 Grain 2. Gold intergrown with sub/euhedral quartz. Note galena inclusions



B) JACR-3 Grain 3. Gold interstitial to sub/euhedral quartz

Figure 2.

Also characteristic of alluvial gold grains, and easily visible in the polished samples examined here, is the presence of Ag-depleted rims. These are best seen when the interior of the gold grain is Ag-rich (i.e. greatest colour difference) and are usually no more than 50 µm wide, though they can appear so if the plane of the polished section is cut obliquely and close to the edge of the grain. In such cases patchy areas of Ag-depletion are visible, usually surrounding cavities which are in effect indentations in the grain. Ag-depleted zones can also occur within the grain where folding has occurred. In some golds, e.g. JACR-9, the Ag-poor rim has a spongy, porous texture. It is generally thought (Desborough, 1970) that Ag-depletion is due to leaching of Ag in the fluvial regime. Others (e.g. Guisti, 1986) suggest that in some cases it is due to Au precipitation. Another possibility is that this margin developed during the residence of the gold grain in the soil or weathering zone prior to release into the drainage system. However, the observations made here are consistent with the first viewpoint. Particularly, the observation that the Ag-depleted margins are developed on rounded grain edges that themselves are clearly due to fluvial action. The boundary between the Ag-depleted zone and the interior is quite abrupt, but often irregular suggesting a chemical diffusive front rather than an old overgrown grain boundary.

Electron-probe analyses of the golds are tabulated in the Appendix and are graphically displayed in Figure 5. Apart from one or two grains (JACR-14, 16) the interiors of the golds are remarkably homogeneous with respect to Ag: Au. This composition is believed to be that of the gold as deposited from solution in the mother mineral deposit. In addition to Au and Ag, Cu and Te were also measured. Cu is generally low (<0.65 atom% or 0.22 wt%) and Te undetectable in all the grains: The figures for Te quoted in the list of data are in fact spurious and due to interference from Ag.

A number of gold grains contained what appear to be primary inclusions, i.e. distinct from quartz and zircon grains trapped in the gold during transport. Those noted and identified are shown in Table 2.

3.2 Alluvial platinum. One sample (JACR-17) was examined consisting of 3 grains. They are less 'platy' in appearance than the gold but show very well rounded and spherical to irregular forms. All three have a similar composition:

Pt	88.8
Fe	5.7
Rh	1.4
Ir	1.3
Pd	1.2
Total	98.4

In addition, inclusions of laurite-erlichmannite [(Os, Ru)S₂] were noted plus one occurrence of a rare or new rhodium sulphide [(Rh, Pt, Ni, Cu)S] possibly related to prassoite (RhS). More detailed probe work is needed to completely characterise this phase.

Gold and Platinum Samples, Ecuador**Table 1a.** Sample locations.

CODE	LOCALITY	PROVINCE
JACR-1	Guaysimi (Primary)	Zamora Chinchipe
JACR-2	Río Yusupino	Napo
JACR-3	Portovelo	El Oro
JACR-4	Río Jatunyacu (Sardinas)	Napo
JACR-5	Jatunyacu	Napo
JACR-6	Río Napo (Pusuno)	Napo
JACR-7	Aguarico (Cascales)	Napo
JACR-8	Río Cabeno (Cerro Negro)	Napo
JACR-9	Río Pilares (Collay)	Azuay
JACR-10	Río Malacatus	Loja
JACR-11	Río Puyango	Loja
JACR-12	Río Chico (Machala)	El Oro
JACR-13	Río San Juan	Carchi
JACR-14	Río Camumbí	Carchi
JACR-15	Río Tulumbí	Esmeraldas
JACR-16	Río Santiago	Esmeraldas
JACR-17	Río Camumbí	Carchi
JACR-18	Zamora Batholith-weathered intrusion with <u>small</u> gold flakes on 'dark' surface	
JACR-19	Nambija skarn with primary gold	

Table 1b. Description of samples.

Alluvial gold samples	
JACR-1	Numerous flakes up to 1mm
JACR-2	1 flake 7mm
JACR-3	5 gold-quartz nuggets 3-7mm
JACR-4	3 flakes 1-4mm
JACR-5	3 flakes 1-2mm
JACR-6	6 flakes 0.2-1mm
JACR-7	4 flakes 0.8-2mm
JACR-8	2 flakes 1.5mm
JACR-9	3 rounded-irregular grains 2-3mm
JACR-10	4 flakes 0.8-2mm
JACR-11	1 flake 5mm
JACR-12	3 flakes 1-2mm + 1 rounded grain 1.2mm
JACR-13	2 flakes 3-4mm
JACR-14	2 flakes 2-6mm
JACR-15	Numerous fine flakes <1mm
JACR-16	5 flakes 0.3-2mm
Alluvial platinum samples	
JACR-17	3 rounded grains 0.4-1.5mm
Rock samples	
JACR-18	Weathered intrusive with limonitic/goethitic coating. Several very small gold grains embedded in Fe oxides.
JACR-19	Garnet skarn with irregular gold

Table 2. Inclusions in gold grains

JACR-3	Grain 1	Common galena plus sphalerite, magnetite
	Grain 2	Galena
JACR-5	Grain 1	Pyrite
JACR-12	Grain 1	Arsenopyrite
	Grain 4	Arsenopyrite
JACR-13	Grain 1	Grandite (garnet)
JACR-15	Grain 3	Galena
	Grain 5	Chalcopyrite
JACR-16	Grain 4	Common bornite plus pyrite, chalcopyrite

3.3 Skarn JACR-19. This is a distinctive gold bearing rock which is illustrated in Figs. 3 and 4. It is predominantly composed of grossular-andradite (grandite) garnet. The rock has a patchy texture and can be viewed as consisting of an array of domains cored by rather fine grained granular grandite and overgrown by larger clear grandite that often displays perfect euhedral forms adjacent to the later interstitial phases, which in turn form a network of irregular veinlets separating the garnet domains. Where two grandite 'domains' abut, without any interstitial phase development, an irregular suture line is apparent. The larger grandite crystals display episodic growth zoning and complex low-order birefringence patterns. The composition of the garnets was measured by probe and the analysis tabulated in the Appendix. They vary from $\text{Ad}_{70}\text{Gr}_{29}$ to $\text{Ad}_{45}\text{Gr}_{55}$, with growth zoning in the direction of higher Ad contents.

Phases forming the interstitial network to the garnet domains are clear quartz, K-feldspar, calcite and gold. Some chlorite is also developed. The feldspar is patchily altered to fine turbid cryptocrystalline material, but probe analysis of the least altered feldspar shows it to be almost pure KAlSi_3O_8 . The calcite has up to a few % Mn. Gold is clearly later than garnet but appears to be contemporaneous with the Qz-Cc-Kfs infilling. Figs. 4A and B show this – note the irregular rather crenulate boundaries between gold and calcite and gold and feldspar, respectively, suggesting co-precipitation.

The gold in this sample does not appear to be associated with any sulphide and is remarkably homogenous with low Ag and undetectable Cu (see Appendix and Figure 5).

3.4 Weathered Intrusive JACR-18. This sample has only been examined optically though any future work should involve SEM analysis in order to cope with its fine-grained nature (in particular). Optical examination shows the gold in this sample to be embedded in the iron hydroxide coating on this rock and to display crude octahedral crystal development. It is closely associated with perfect tiny prisms of quartz that have clearly grown into spaces and vugs. Thus, this gold is almost certainly of low temperature, supergene origin and would be expected to have a very high fineness (i.e. low Ag). SEM work should confirm or repudiate this.

4. Discussion

Detailed information on the geology of Ecuador and in particular of the localities from where the gold samples are derived is unavailable to the author, so this discussion in relating gold composition to host deposit will be in broad terms.

The composition of the Ecuador golds varies widely, from 1-2% Ag up to 60 atom% (Fig. 5). Individual samples can also show a wide range of composition although, as noted above, individual grains are usually very homogeneous. Other samples, e.g. JACR-1, show tight grouping. Thus, it seems likely a variety of types of gold deposit have been sampled.

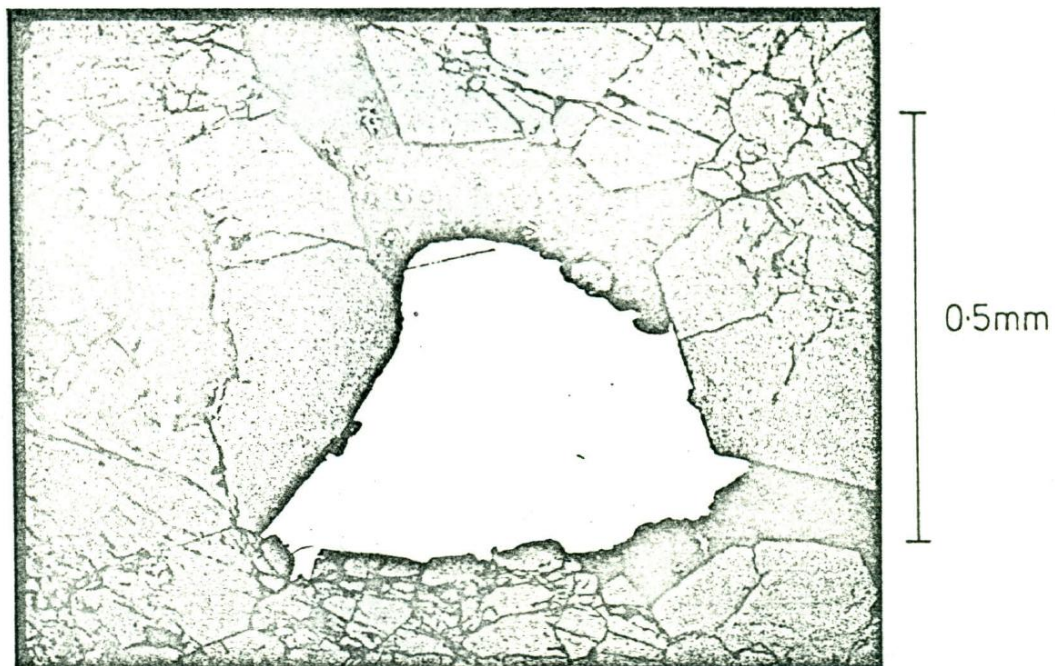


A) Transmitted light



B) Reflected light

Figure 3. Gold in JACR-19 skarn. Gold, quartz and feldspar interstitial to garnet



A) Gold + calcite interstitial to garnet



B) Gold + K-feldspar interstitial to garnet

Figure 4. Gold in skarn JACR-19

The factors controlling the Au/Ag ratio of native gold are not known at all well. However, a first overriding control must be the availability of the two metals. Thus, native gold will tend to reflect the bulk Au/Ag of the deposit. More detailed mineralogical control will be exercised by the local paragenesis. For example, in many skarn and Cu-porphyry deposits native gold is the only phase with major Au or Ag, however, Au/Ag in gold is invariably greater than bulk Au/Ag of the deposit. This can be related to preferential partitioning of Ag into phases such as bornite and chalcopyrite. In telluride systems where other Au-Ag phases occur, such as hessite, petzite or calaverite, native gold composition can be strongly buffered. Cu content similarly reflects the availability of Cu in the mineralizing solutions and its partitioning amongst various phases. Thus, gold associated with Cu-sulphides usually has significant Cu content. The tendency for Cu to vary antipathetically with Ag in gold correlates with the fact that Ag-rich deposits tend to be Cu poor, and vice versa.

Figure 6. show some comparative data resulting from earlier work by the author with which comparison can be made to the Ecuador samples. The styles of mineralisation supplying some of the Sumatran (Fig. 6c-g) golds are well constrained. Fig. 6c gold contains the highest Cu content and is derived from a Cu-skarn in which bornite and chalcopyrite are prominent phases. This deposit has a bulk Au:Ag close to 1:1. Gold in Fig. 6d is high level remobilised or supergene in origin and is derived from limonitic coatings in volcanic rocks where it shows good octahedral crystal development. This is closely analogous to gold in sample JACR-18. Fig. 6e gold derives from two areas in Sumatra both characterised by extensive quartz vein development in greenstone/greenschist rocks close to major faults with transducted serpentinite slices. These areas also contain some calc-alkalic plutonic activity. Figs. 6f and g are examples of Tertiary epithermal vein deposits. The Mangani deposit in particular has a bulk Au/Ag ratio of 1/20 or less and native gold-silver is associated with a suite of Ag sulphides and sulphosalts.

The Costa Rica gold from the Osa peninsula has been shown by Berrange (1984) to derive from vein development within rocks of oceanic affinity with no superimposed calc-alkalic activity, and this is thought to be reflected in the low Ag contents of all the samples analysed. This correlation of Ag content with the crustal maturity within an orogenic zone is manifested in the generally known fact that Ag is concentrated over Au in younger and shallower metal deposits (Boyle, 1977).

Data from the literature is rather sparse, although Antweiler & Campbell (1977) have made a study relating bulk gold analyses (as distinct from probe) to the environment of mineralisation. They generally confirm what was said above, showing that epithermal gold has 35-50 %Ag, whereas pyrometasomatic (skarn) and mesothermal gold has less Ag. Gold from copper porphyries they show to have 35-40% Ag but significant Cu compared to epithermal gold. Gold from two porphyries in Canada has 20-30% Ag according to Cuddy and Kesler (1982).

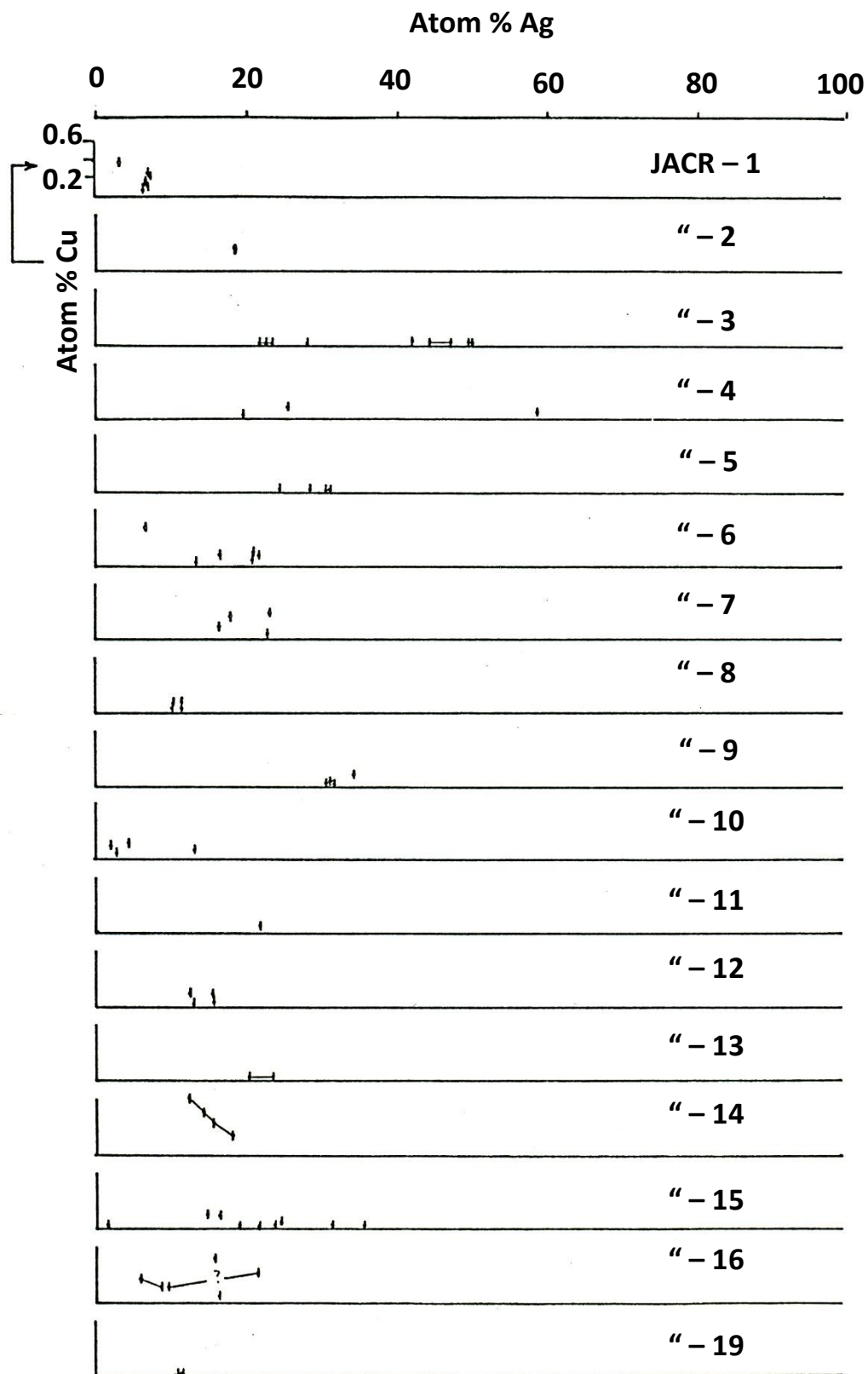


Figure 5. Gold compositions

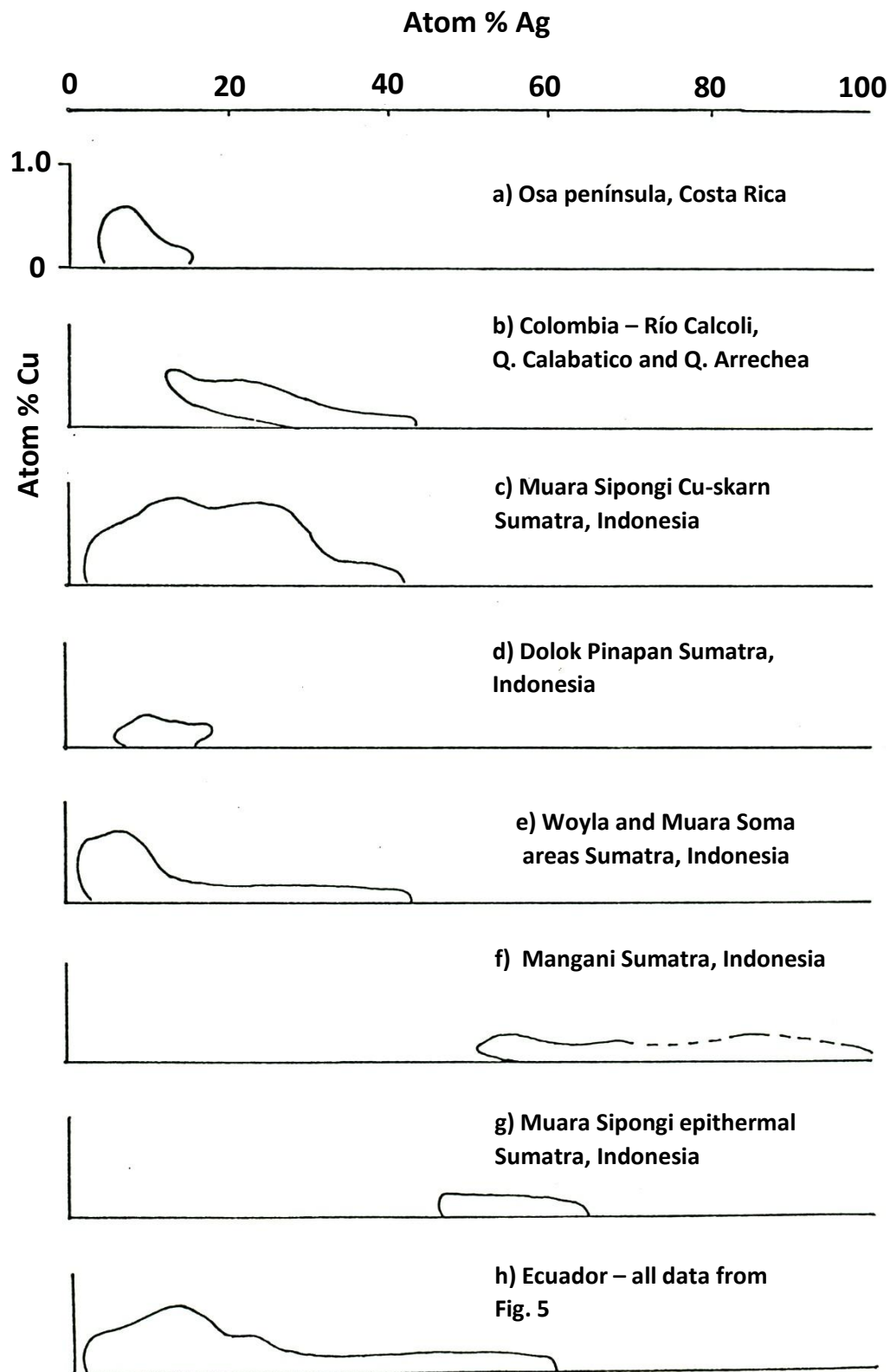


Figure 6. Gold compositional fields for comparison with the Ecuador data

Turning now to Ecuador, it will be appreciated that it is not possible to characterise each sample in turn of its host deposit. A few indications can be made, however, JACR-19 shows that gold derived from one specific garnet skarn has a low Ag content and also low or zero Cu. The garnet compositions of this skarn are typical of Fe- and Cu-skarns as defined by Einaudi et al. (1981) and similar to the Muara Sipongi Cu-skarn. The gold in this sample though is unrelated to sulphide deposition and does not show the higher Cu contents of some skarn gold. Samples 14 and 16 are distinct in that they do show significant Cu, some intragrain variability and in the case of 16 there are also common inclusions of Cu sulphide. A Cu-skarn or Cu-porphyry origin for these golds would be appropriate. JACR-3 is an interesting sample in that all the grains represent fragments of quartz-gold vein material (see description above and Fig. 2). Galena and sphalerite inclusions occur and three of the grains have the high Ag, low Cu characteristic of epithermal base contains one grain that has epithermal/sub-volcanic affinity. The remaining samples tend to be undistinguished although JACR-12 gives indications of a gold-bearing arsenopyrite vein deposit (cf. Table 2). The generally low Ag of this group of samples probably rules out young (?Tertiary) epithermal/sub-volcanic deposits, but are consistent with some porphyry deposits or mesothermal quartz-gold lodes developed in somewhat older metavolcano-sedimentary basement.

Clearly, detailed knowledge of the geological provenance of the samples would aid interpretation, together with stream sediment geochemistry and heavy mineral analysis (etc.), and it would be anticipated that at longer term, more substantial study would invoke these. However, it is hoped that this pilot study has shown that detailed examination alluvial/in situ gold can place significant constraints on interpretation relating to the search for gold and other metal deposits.

Finally, the platinum samples JACR-17 indicates a deposit associated with basic/ultrabasic igneous rocks, such as ophiolites in the orogenic environment. The Pt-Fe alloy phase is a common constituent of most PGM deposits. Of interest, as noted above, is the Rh-sulphide and also the significant Rh content of the Pt metal. Rh is often the least abundant PGM (Cabri, 1981) and it is possible that JACR-17 indicates a Rh-rich source. This aspect is worthy of follow-up work.

Acknowledgements.

R. D. Fakes prepared the polished grain mounts and thin sections.

5. Electron microprobe analyses

The following analyses were made on the Microscan 5 electron microprobe in the Dept of Geology, University of Edinburgh. Gold was analysed for Au, Ag, Cu and Te. The detection level for Cu is about 0.04%. Te is affected by interference from Ag but it was found that in all the grains Te is below detection level; thus, the Te values in the following Tables should be ignored.

Grandite garnet and K-feldspar from JACR-19 were also analysed and the results tabulated here. Garnet analyses were recalculated assuming exactly 8.0 cations and 12.0 oxygens. This allows Fe³⁺ and Fe²⁺ to be calculated and the garnet end-members to be assigned.

Table 3. JACR-1, 2, 3, 4 electron microprobe analyses

Sample	Grain	Cu WT % EL	Cu ATOM	Ag WT % EL	Ag ATOM	Au WT % EL	Au ATOM	Te WT % EL	Te ATOM
JACR-1	1(A)	0.07	0.207	4.30	7.507	96.49	92.256	0.02	0.030
	1(B)	0.03	0.089	4.21	7.343	96.9	92.554	0.01	0.015
	2(A)	0.09	0.269	4.12	7.254	95.86	92.432	0.03	0.045
	2(B)	0.04	0.119	4.18	7.305	96.65	92.502	0.05	0.074
	3(A)	0.05	0.148	4.37	7.613	96.68	92.239	0.00	0.000
	3(B)	0.05	0.149	4.33	7.592	96.00	92.185	0.05	0.074
	4(A)	0.13	0.39	1.90	3.36	99.30	96.175	0.05	0.075
	4(B)	0.13	0.393	2.05	3.647	98.46	95.916	0.03	0.045
	5(A)	0.01	0.03	3.88	6.863	96.11	93.107	0.00	0.00
	5(B)	0.04	0.119	3.87	6.789	96.83	93.032	0.04	0.059
JACR-2	1(A)	0.09	0.257	10.82	18.216	88.30	81.413	0.08	0.114
	1(B)	0.07	0.200	10.90	18.334	88.44	81.466	0.00	0.000
	1(C)	0.07	0.200	10.85	18.287	88.17	81.384	0.09	0.128
JACR-3	1(A)	0.02	0.049	34.91	50.051	63.26	49.670	0.19	0.230
	1(B)	0.00	0.000	34.61	49.843	63.27	49.901	0.21	0.256
	1(C)	0.03	0.073	34.47	49.557	63.71	50.163	0.17	0.207
	2(A)	0.00	0.000	13.21	21.877	85.92	77.927	0.14	0.196
	2(B)	0.00	0.000	14.34	23.547	84.83	76.286	0.12	0.167
	2(C)	0.00	0.000	13.71	22.624	85.42	77.195	0.13	0.181
	3(A)	0.00	0.000	17.50	28.04	81.82	71.797	0.12	0.163
	3(B)	0.00	0.000	17.27	27.768	81.89	72.110	0.09	0.122
	4	0.03	0.076	28.32	42.146	70.66	57.590	0.15	0.189
	5(A)	0.00	0.000	29.90	44.33	68.27	55.432	0.19	0.238
	5(B)	0.00	0.000	32.16	47.239	65.31	52.538	0.18	0.224
JACR-4	1(A)	0.04	0.111	15.58	25.400	83.32	74.392	0.07	0.096
	1(B)	0.04	0.111	15.71	25.620	83.02	74.146	0.09	0.124
	2	0.00	0.000	11.82	19.758	87.53	80.129	0.08	0.113
	3(A)	0.02	0.046	43.32	58.576	55.43	41.047	0.29	0.331
	3(B)	0.03	0.069	43.76	58.927	55.20	40.708	0.26	0.296

Table 4. JACR-5, 6, 7, 8, 9, 10, 11 electron microprobe analyses

Sample	Grain	Cu WT % EL	Cu ATOM	Ag WT % EL	Ag ATOM	Au WT % EL	Au ATOM	Te WT % EL	Te ATOM
JACR-5	1(A)	0.00	0.000	17.68	28.485	80.82	71.311	0.15	0.204
	1(B)	0.01	0.027	17.66	28.314	81.38	71.455	0.15	0.203
	2(A)	0.00	0.000	14.94	24.451	84.15	75.424	0.09	0.125
	2(B)	0.00	0.000	15.01	24.711	83.38	75.177	0.08	0.111
	3(A)	0.00	0.000	19.58	31.321	78.15	68.463	0.16	0.216
	3(B)	0.00	0.000	19.01	30.588	78.57	69.235	0.13	0.177
JACR-6	1(A)	0.05	0.143	11.94	20.093	86.47	79.693	0.05	0.071
	1(B)	0.03	0.085	12.07	20.219	86.78	79.611	0.06	0.085
	2	0.02	0.059	7.62	13.254	90.99	86.673	0.01	0.015
	4	0.05	0.140	13.04	21.557	86.38	78.205	0.07	0.098
	5	0.14	0.418	3.66	6.437	96.65	93.086	0.04	0.059
	6	0.05	0.143	10.02	16.918	89.62	82.868	0.05	0.071
JACR-7	1(A)	0.05	0.144	9.56	16.232	89.81	83.509	0.08	0.115
	1(B)	0.04	0.116	9.41	16.053	89.62	83.730	0.07	0.101
	2	0.09	0.256	10.60	17.766	89.19	81.865	0.08	0.113
	3	0.11	0.307	13.99	23.007	84.99	76.546	0.10	0.139
	4	0.01	0.028	13.45	22.292	85.41	77.526	0.11	0.154
JACR-8	1(A)	0.02	0.059	6.71	11.674	92.56	88.193	0.05	0.074
	1(B)	0.04	0.118	6.58	11.398	93.20	88.412	0.05	0.073
	2(A)	0.04	0.119	5.72	10.023	93.61	89.829	0.02	0.030
	2(B)	0.01	0.03	5.77	10.058	94.14	89.868	0.03	0.044
JACR-9	1(A)	0.06	0.159	21.87	34.140	76.65	65.529	0.13	0.172
	1(B)	0.05	0.132	21.98	34.241	76.80	65.522	0.08	0.105
	2(A)	0.01	0.027	19.82	31.421	78.82	68.432	0.09	0.121
	2(B)	0.00	0.000	19.37	30.797	79.29	69.041	0.12	0.161
	3(A)	0.00	0.000	20.27	31.947	78.55	67.800	0.19	0.253
	3(B)	0.00	0.000	20.03	31.635	78.79	68.151	0.16	0.214
JACR-10	1	0.03	0.087	7.51	12.820	93.16	87.093	0.00	0.000
	2	0.04	0.122	1.13	2.026	99.67	97.853	0.00	0.000
	3	0.06	0.181	2.27	4.042	98.20	95.762	0.01	0.015
	4	0.00	0.000	1.41	2.523	99.49	97.477	0.00	0.000
JACR-11	1(A)	0.01	0.028	13.02	21.389	87.22	78.472	0.08	0.111
	1(B)	0.03	0.084	12.92	21.366	86.61	78.438	0.08	0.112
	1(C)	0.00	0.000	13.00	21.520	86.49	78.410	0.05	0.07

Table 5. JACR-12, 13, 14, 15, 16, 19 electron microprobe analyses

Sample	Grain	Cu WT % EL	Cu ATOM	Ag WT % EL	Ag ATOM	Au WT % EL	Au ATOM	Te WT % EL	Te ATOM
JACR-12	1(A)	0.04	0.115	9.34	15.838	90.35	83.904	0.10	0.143
	1(B)	0.04	0.115	9.30	15.738	90.72	84.076	0.05	0.072
	2(A)	0.05	0.147	7.18	12.408	92.32	87.372	0.05	0.073
	2(B)	0.05	0.146	7.32	12.597	92.48	87.156	0.07	0.102
	3	0.00	0.000	7.43	12.974	90.97	86.996	0.02	0.030
	4(A)	0.02	0.580	9.16	15.631	90.17	84.268	0.03	0.043
	4(B)	0.02	0.058	9.21	15.605	90.83	84.281	0.04	0.057
JACR-13	1(A)	0.03	0.085	12.19	20.295	87.20	79.508	0.08	0.113
	1(B)	0.00	0.000	13.90	23.039	84.69	76.877	0.06	0.084
JACR-14	1(A)	0.22	0.657	7.01	12.323	90.33	86.961	0.04	0.059
	1(B)	0.08	0.231	10.55	17.927	87.82	81.727	0.08	0.115
	1(C)	0.17	0.502	8.06	14.027	89.60	85.397	0.05	0.074
	1(D)	0.13	0.378	9.01	15.424	89.76	84.154	0.03	0.043
JACR-15	1	0.05	0.144	9.66	16.378	89.81	83.392	0.06	0.086
	2	0.00	0.000	23.14	35.563	76.39	64.294	0.11	0.143
	3	0.05	0.145	8.71	14.844	90.99	84.925	0.06	0.086
	4	0.00	0.000	13.06	21.695	85.95	78.193	0.08	0.112
	5	0.02	0.055	15.14	24.629	84.26	75.068	0.18	0.248
	6	0.00	0.000	14.57	23.789	85.00	76.004	0.15	0.207
	7	0.00	0.000	11.30	18.893	88.36	80.909	0.14	0.198
	8	0.00	0.000	20.00	31.621	78.74	68.179	0.15	0.200
	9	0.00	0.000	0.84	1.520	99.31	98.419	0.04	0.061
JACR-16	1(A)	0.00	0.000	9.52	16.248	89.56	83.709	0.03	0.043
	1(B)	0.01	0.29	9.50	16.150	89.94	83.735	0.06	0.086
	2(A)	0.06	0.178	5.37	9.403	94.16	90.300	0.08	0.118
	2(B)	0.12	0.339	12.93	21.498	85.64	77.98	0.13	0.183
	3	0.18	0.519	9.37	15.902	89.85	83.508	0.05	0.072
	4(A)	0.06	0.179	5.04	8.837	94.69	90.925	0.04	0.059
	4(B)	0.09	0.271	3.22	5.703	96.89	93.981	0.03	0.045
JACR-19	1	0.00	0.000	6.53	11.314	93.46	88.686	0.00	0.000
	2	0.00	0.000	6.38	11.061	93.67	88.939	0.00	0.000
	3	0.01	0.029	6.35	11.014	93.63	88.942	0.01	0.015
	4	0.00	0.000	6.42	11.197	92.97	88.803	0.00	0.000
	5	0.00	0.000	6.25	10.901	93.28	89.099	0.00	0.000
	6	0.00	0.000	6.38	11.112	93.11	88.814	0.05	0.074
	7	0.00	0.000	6.25	10.894	93.28	89.047	0.04	0.059
	8	0.00	0.000	6.39	11.140	92.98	88.772	0.06	0.088
	9	0.00	0.000	6.64	11.471	93.51	88.471	0.04	0.058

Table 6. K-feldspar analyses – JACR-19 skarn. 12 Feb 87

	FL # 1	FL # 2	FL # 3
SiO₂	63.74	63.94	65.51
Al₂O₃	17.85	17.86	18.03
FeO	0.00	0.04	0.01
CaO	0.00	0.00	0.00
Na₂O	0.14	0.15	0.11
K₂O	16.81	16.65	16.78
TOTAL	98.54	98.64	100.44
Atomic proportions based on 8.0 oxygens			
Si	3.001	3.004	3.017
Al	0.990	0.989	0.978
Fe	0.000	0.002	0.000
Ca	0.000	0.000	0.000
Na	0.013	0.014	0.010
K ₂	1.010	0.998	0.986
SUM	5.014	5.007	4.991
An	0.00	0.00	0.00
Ab	1.25	1.35	0.99
Or	98.75	98.65	99.01

Table 7. Garnet analyses – JACR-19 skarn. 12 Feb 87

	GT # 1A	GT # 1B	GT # 2	GT # 3A	GT # 3B	GT # 4A	GT # 4B
SiO₂	37.2	36.39	37.37	36.6	36.06	37.82	36.89
TiO₂	0.31	0.32	0.12	0.22	0.2	0.29	0.23
Al₂O₃	10.28	6.53	9.81	6.57	5.72	11.3	6.21
Cr₂O₃	0.01	0.03	0.03	0.02	0.04	0.01	0.04
FeO	15.07	19.51	15.76	19.89	20.66	13.75	19.94
MnO	0.88	0.85	0.98	0.59	0.49	1.06	0.73
MgO	0.04	0.02	0.03	0.03	0.03	0.03	0.04
CaO	34.71	34.26	34.49	34.4	34.03	34.8	34.07
TOTAL	98.5	97.91	98.59	98.32	97.23	99.06	98.15
Atomic proportions based on 12.0 oxygens							
Si	3.107	3.15	3.129	3.155	3.163	3.113	3.184
Ti	0.019	0.021	0.008	0.014	0.013	0.018	0.015
Al	1.012	0.666	0.968	0.667	0.591	1.096	0.632
Cr	0.001	0.002	0.002	0.001	0.003	0.001	0.003
Fe	1.053	1.412	1.104	1.434	1.516	0.946	1.439
Mn	0.062	0.062	0.07	0.043	0.038	0.074	0.053
Mg	0.005	0.003	0.004	0.004	0.004	0.004	0.005
Ca	3.107	3.178	3.094	3.177	3.199	3.069	3.151
SUM	8.366	8.494	8.378	8.496	8.527	8.321	8.482
Atom. Props. based on 8.0 Cats and 12.0 Oxy							
Si	2.977	2.975	2.991	2.977	2.976	2.995	3.004
Ti	0.019	0.02	0.007	0.013	0.012	0.017	0.014
Al	0.969	0.629	0.925	0.63	0.556	1.054	0.596
Cr	0.001	0.002	0.002	0.001	0.003	0.001	0.003
Fe₃⁺	1.009	1.334	1.055	1.353	1.426	0.911	1.358
Fe	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Mn	0.06	0.059	0.066	0.41	0.034	0.071	0.050
Mg	0.005	0.002	0.004	0.004	0.004	0.004	0.005
Ca	2.976	3.001	2.958	2.998	3.009	2.953	2.973
Al₄	0.023	0.025	0.009	0.023	0.024	0.005	0.004
Al₈	0.946	0.604	0.917	0.607	0.532	1.049	0.6
And	49.8	65.3	52.3	66.7	70.2	45.1	67.3
Gro	48.1	32.7	45.4	31.8	28.6	52.4	30.9
Pyr	0.2	0.1	0.1	0.1	0.1	0.1	0.2
Alm	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Spe	2.0	1.9	2.2	1.3	1.1	2.3	1.7

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APPENDIX 4

BRITISH GEOLOGICAL SURVEY

MINERAL SCIENCES AND ISOTOPE GEOLOGY
RESEARCH GROUP
ISOTOPE GEOLOGY UNIT

Report No. 87/5

by

C. C. Rundle

Reconnaissance Potassium – Argon ages
for the Cordillera Real Project, Ecuador

1. Introduction

As a preliminary K-Ar investigation prior to a trip to Ecuador to collect samples for a detailed geochronological study, 10 samples of separated minerals from various rock bodies encountered during preliminary geological traverses were received from Dr. John Aspden of the Cordillera Real Project. Unfortunately, it appears that the mineral separation facilities in Quito were not ideal and the so-called mineral separates were of very poor quality; several consisting almost entirely of magnetite. Accompanying the separates were small hand specimens, but no thin sections, rock descriptions, mineral identification, or details of the geological relationships of the various specimens.

In the Isotope laboratory in London the samples were examined and an attempt was made to identify the rocks and the minerals (thanks for assistance to Mr. I. L. Miller); with the following conclusions:

Sample No.	Description
AD. ML4	Hornblende diorite. Mostly hornblende, but contaminated with biotite, feldspar, and ca. 2% magnetite.
AD. ML5	Granodiorite. Hornblende + feldspar with 90% magnetite.
FV. 11	Granite. Biotite + feldspar with 70% mag
FV. 15	Granodiorite. Hornblende, traces of biotite and feldspar, 50% magnetite.
FV. 34	Granodiorite. 90% Biotite, traces of magnetite and feldspar.
FV. 57	Orthogneiss, ditto.
FV. 58	As above
FV. 60	Hornblende granite. Hornblende + feldspar with 90% magnetite
FV. 83	Hornblende diorite/?gabbro. As above. 50% magnetite
386. 13. CO	Mostly magnetite – even the lump of rock could be picked up with a hand magnet! Some amphibole.

After examination of the separates the magnetite was removed using a hand magnet, and the minerals were further purified using heavy liquid separations. This produced a reasonably pure mineral concentrate in all cases and these were then analysed for Potassium content (in duplicate) by dissolving in mixed perchloric and hydrofluoric acids and estimating the K using a digital flame photometer with lithium internal standard.

For the first eight samples the potassium result suggested a reasonably pure fresh mineral (except that FV. 11 is rather low-K), but the 'biotite' from FV. 83 has a very low K content and must therefore be highly chloritised, while the amphibole from 13.CO has only 0.03%K, almost below the detection limit for the method, and is useless for dating purposes; it could be that this sample is actinolite rather than hornblende. Nine samples were analysed for Argon content and the K-Ar apparent ages were calculated using the decay and other constants recommended by Steiger and Jäger (Earth Planet. Sci. Lett. 36, 1977, pp. 356-362). As a test of reproducibility two samples were analysed for argon in duplicate.

2. Results

Sample	Mineral	%K	Atmos. 40 Ar (%)	Rg. 40Ar (nl/g)	Age $\pm 2\sigma$
AD. ML4	Hornblende	0.757	26.9	5.26	171 $\pm$ 5
AD. ML5	Hornblende	0.755	47.6	5.21	169 $\pm$ 6
FV. 11	Biotite	4.84	35.0	9.85	52 $\pm$ 2
			37.7	9.71	51 $\pm$ 2
FV. 15	Hornblende	0.702	69.8	1.82	66 $\pm$ 4
			63.8	1.70	61 $\pm$ 4
FV. 34	Biotite	6.83	35.8	15.8	59 $\pm$ 2
FV. 57	Biotite	5.96	27.3	19.7	83 $\pm$ 2
FV. 58	Biotite	6.46	24.6	24.9	97 $\pm$ 3
FV. 60	Hornblende	0.570	35.7	3.49	151 $\pm$ 5
FV. 83	?Biotite	2.31	46.4	3.52	39 $\pm$ 4
386. 13. CO	Amphibole	0.03	-	-	-

3. Discussion

In view of the lack of geological information about these samples it is very difficult to assess the significance, or reliability of these results. Undoubtedly the low K 'biotite' from FV. 83 will have been subject to post-crystallisation loss of argon and the age can only be regarded as a very poor minimum for the formation of this specimen; but the same argument may also apply, probably to a lesser extent, to that from FV. 11.

The two hornblende samples, ML4 and ML5 (which, in view of the similarities in number and rock type are presumably related) have given the oldest ages in this study and good agreement between the two specimens. The age is mid-Jurassic. It is not possible to tell from these data whether this represents an igneous or a metamorphic event.

The hornblende from FV. 60 is significantly younger than this, and that from FV. 15 younger still, and the three high-K Biotite samples have given a spread in ages which scatter between these two results. This pattern of ages is strongly suggestive of differential partial argon loss from the different phases during a later regional metamorphic event; possibly at ca. 60 Ma (Paleocene) – or later if the date from FV. 11 is considered to be reliable (52 Ma; Eocene – Paleocene boundary).

Further K-Ar dating of Hornblende/biotite pairs from the same rock, Rb-Sr whole-rock dating, and (possibly) U-Pb dating of zircons, plus detailed discussions with the field geologists, should help to clarify the precise significance of these results.

C.C. Rundle

6th April 1987

APPENDIX 5

Petrography of 8 Samples
from the Río Mulatos

for

Area Selection Group
B.P. Minerals International
Newbury, Berkshire

Anne Thompson
Consultant
Flexford Court Cottage
Highclere, Newbury
Berkshire

3 May 1987

SAMPLE LIST

140-b	-	'phyllite'
148	-	biotite schist
147-a	-	granodiorite
154-a	-	diorite
145-c	-	skarn
149	-	skarn
151	-	skarn
156	-	skarn

140-b – ‘phyllite’

Hand Specimen

Black with strong foliation, slightly greasy surface. Dark grey nodules up to 1cm across. Fe oxide and fresh pyrite concentrated in stringers and clots. Non-magnetic.

Thin Section

Major Minerals:

-chlorite: pale yellow-green, 1st order birefringence, straight extinction. Two phases; fibrous, foliated mixed with fine disseminated opaques and coarser chlorite, rimming garnet zones, x-cutting foliation. 50%. See Figure 1.

-garnet: pale pink slightly anisotropic-grossular-andradite. Large grains cut by chlorite zones and rimmed by fibrous chlorite. 30%

-quartz: mosaic, mainly in rimming zones, 3%.

Minor Minerals:

-pyrite: along rims of garnet zones, also enclosing chlorite.

-hematite: around pyrite

Garnet is altering to chlorite + quartz and the garnet zones are not disruptive of the general foliation. The second chlorite phase does cut across the foliation and also contains garnet and quartz grains. This chlorite is greener in colour and probably more iron rich than the fibrous variety.



Figure 1. Slightly corroded garnet on far left and coarse chlorite center, cross-cutting foliated chlorite and opaques. 4mm across.

148 – Biotite (tourmaline) schist

Hand Specimen

Black, fine to medium grained with distinct foliation and small (1mm) porphyroblasts (?). Disseminated coarse grained pyrite.

Thin Section

Major Minerals:

-biotite: pleochroic pale brown to chestnut brown, plates up to 2mm, parallel to foliation. 25%.

-tourmaline: pleochroic slate blue to colourless, greatest absorption perpendicular to polarizer, -2ve, straight extinction. Rosettes, concentrated in one half of slide. 25%. See Figure 2.

-quartz: mosaic, recrystallized. 22%.

-chlorite: pale green, straight extinction. 12%.

Minor Minerals:

-calcite: veinlet, cross-cutting tourmaline zone. tc. <1%. See Figure 2.

-pyrite : coarse, disseminated, 3%.

Biotite and chlorite are foliated; tourmaline is undeformed and is the product of metasomatism induced by the granodiorite intrusive.

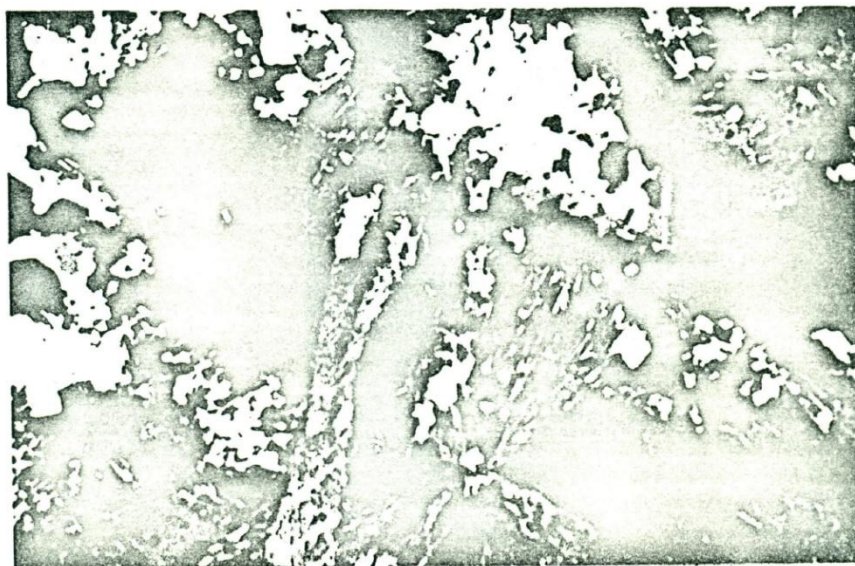


Figure 2. Tourmaline rosettes and quartz mosaic cross-cut by carbonate veinlet. Crossed-polars, 4mm across.

147-a – Granodiorite

Hand Specimen

Dark grey-green and pale grey-white rock, medium grained. 30% mafic, non-magnetic. Uniform texture, moderately deformed.

Thin Section

Major Minerals:

-plagioclase: remnant feldspar with multiple twinning, extinction angle less than 15° , probable albite, also anti-perthite. Dominantly altered to epidote/clinozoisite. Originally 45%. See Figure 3.

-quartz: strained, 20%.

-biotite: pleochroic, pale brown to dark brown, large plates up to 2mm and as secondary alteration of hornblende. 12%. See Figure 4.

-hornblende: pleochroic, green, subhedral, grains. 5mm across, rims appear to alter to actinolite than biotite. 8%. See Figure 4.

Minor Minerals:

-sphene: trace

Sub-parallel alignment of feldspars, moderately deformed. Probable early potassic alteration overprinted by retrograde propylitic alteration.

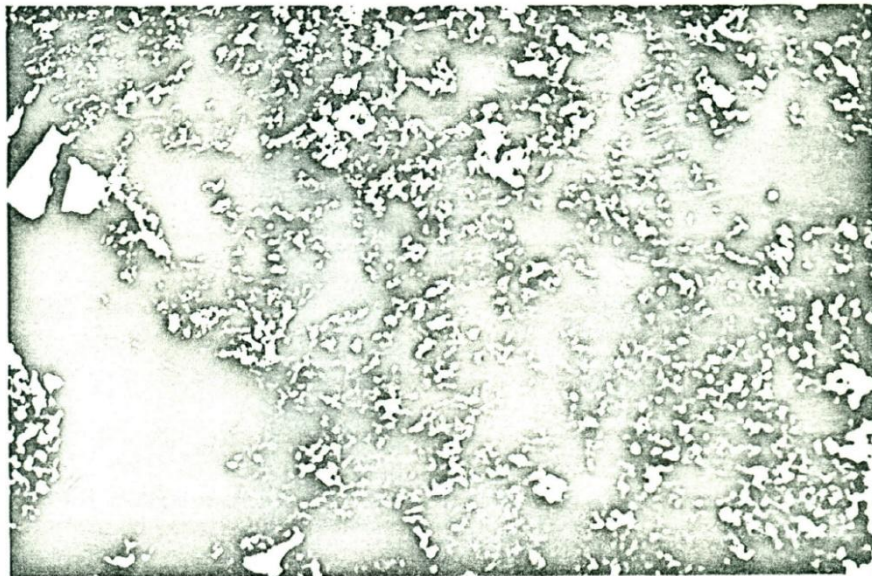


Figure 3. Epidote/clinozoisite altered plagioclase, showing remnant twinning in upper portion of photograph. Biotite in lower left-hand corner. Crossed polars, photo 4mm across.



Figure 4. Altered and deformed granodiorite. Biotite in center left, partially surrounding hornblende. Highly altered plagioclase on right and in center of photo. Plane light, photo 4mm across.

154-a – sericitized diorite-granodiorite

Hand Specimen

Medium to coarse grained, pale green-grey mottled rock. Approx. 30% mafic and non-magnetic. Uniform texture.

Thin Section

Major Minerals:

- plagioclase: highly sericitized, occasional remnants-multiple twinning, extinction angle less than 15°, probable albite. Original crystals 1-2mm. 50%.
- quartz: strained, 20%.
- biotite: pleochroic pale green to dark brown, undulatory flakes, intermixed with phlogopite. 8%. See Figure 5.
- sericite: fine grained masses, replacing feldspar. 45%, see Figure 5.
- chlorite: pale green, straight extinction, in veinlets and clots, 10%.

Minor Minerals:

- epidote: high relief and birefringence, fine grained, inter-mixed with sericite, 3%.
- sphene: trace
- pyrite: disseminated, 1-2%.

Strongly altered diorite, with albitized and sericitized feldspar and minor epidote. Minor deformation.

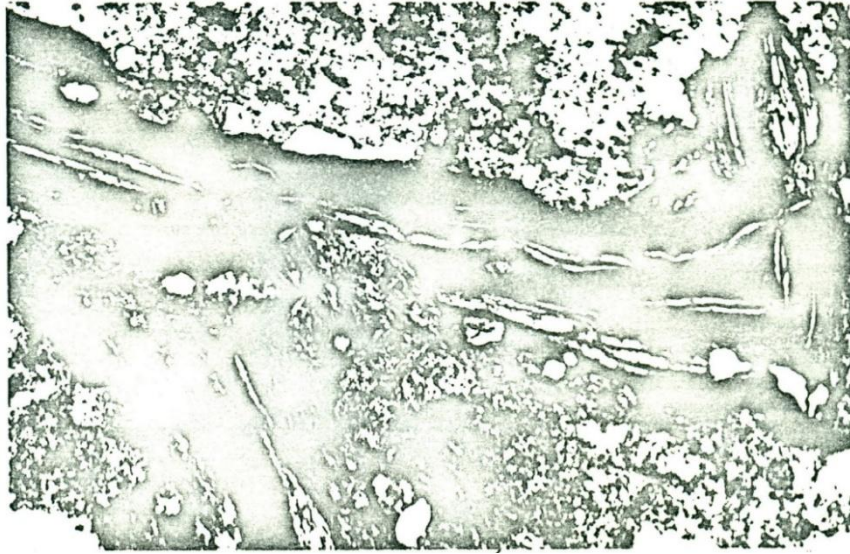


Figure 5. Biotite and sericitized plagioclase, plane light. Photo 4mm across.

145-c – calcic magnetite skarn

Hand Specimen

Pale green and grey mottle rock with a sugary/granular texture. Sample is cut by a 1.5cm, coarsely crystalline magnetite vein (not in thin section). Pyrrhotite (brassy) disseminated, 1-2%.

Thin Section

Major Minerals:

-clinopyroxene: hedenbergite; +2ve, 30° extinction, pleochroic pale green to deep green. Anhedral-subhedral, crystals up to 0.5mm, 25%. See Figure 6.

-calcite: rhombohedral, anomalous interference colours, dispersed and in cross-cutting veinlet. 30%.

-epidote: high-relief, strong interference colours, 12%.

Minor Minerals:

-quartz: trace <1%

-pyrrhotite: disseminated, 2%

Hedenbergite and epidote are intergrown and are the result of prograde skarn formation. Calcite, quartz, magnetite, and pyrrhotite are retrograde.

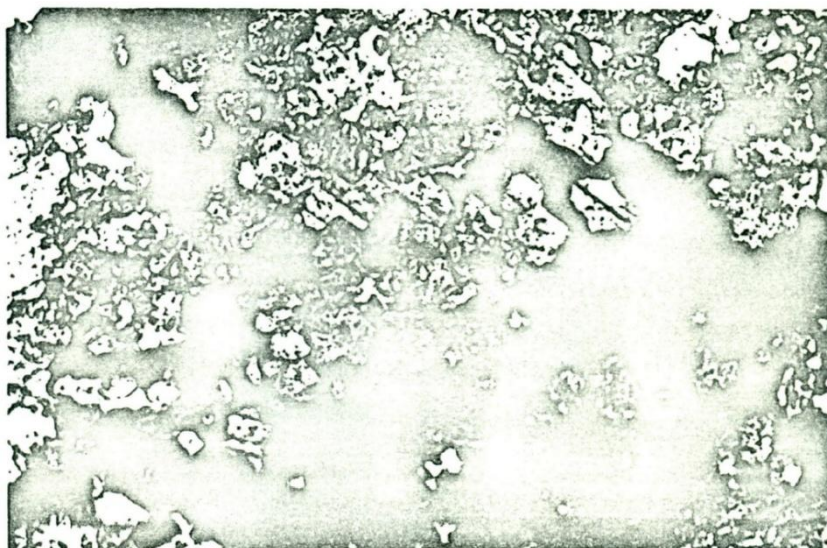


Figure 6. Hedenbergite, green to olive green in lower right and upper left. Matrix of calcite (white) and epidote (pale yellow). Opaques are magnetite. Plane light, photo 4mm across.

149 – calcic magnetite skarn

Hand Specimen

Fine to medium grained black skarn with clots of epidote (20-30%) and disseminated pyrrhotite. Weakly magnetic.

Thin Section

Major Minerals:

- amphibole-ferrohastingsite: pleochroic pale yellow-green to deep blue green, -2ve, extinction angle 20°. 45%. See Figure 7.
- epidote: pale yellow-green, high relief and birefringence, 22%.
- quartz: mosaic, recrystallised, with inclusions of amphibole.
- clinopyroxene: grass green pleochroic, extinction angle 40°, 2nd order birefringence, twinned, strained. Locally anomalous interference colours. Corroded along edges and fractures, altering to phyllosilicate (Brown chlorite) 5%.

Minor Minerals:

- diopside: colourless, wide biaxial figure, extinction angle 40°, 2%.
- wollastonite: colourless, moderate relief, -2ve, 1st order birefringence, straight extinction. 2%
- chlorite: alteration product along edges of clinopyroxene.
- ankerite: high-relief and birefringence, rhombohedral cleavage, 1%.
- sphene: trace.
- pyrrhotite: disseminated, 3%.
- magnetite: disseminated, 2-3%.

This is a complex skarn, with apparent prograde epidote, pyroxene (hedenbergite and diopside) and possibly wollastonite and quartz. Retrograde minerals include amphibole, quartz, chlorite and ankerite. See Figure 7.

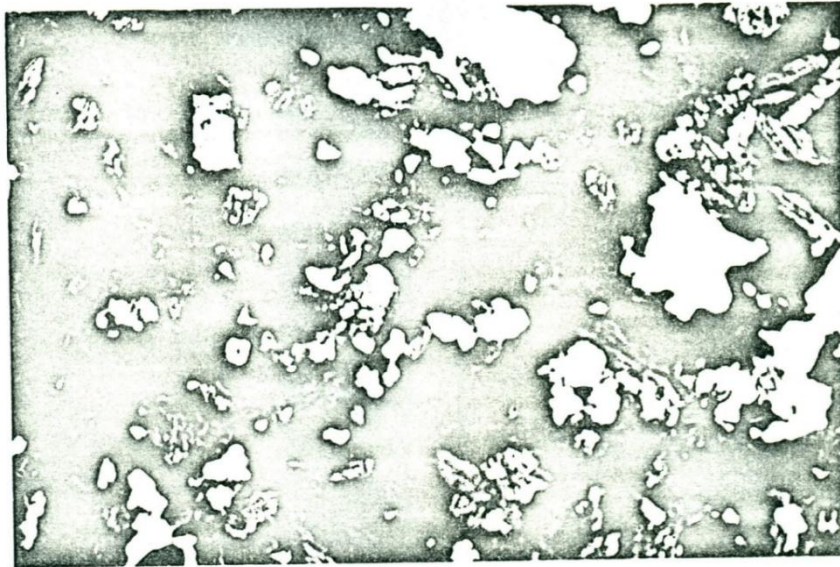


Figure 7. Complex skarn with ferrohastingsite (deep blue green-olive green) and disseminated opaques.

151 – calcic magnetite skarn

Hand Specimen

Largely epidote vein with selvage of black, amphibole garnet skarn.
Weakly magnetic.

Thin Section

Major Minerals:

- epidote: high relief and birefringence, grains up to 0.5mm. Epidote zone cut by fractures. 60%. See Figure 8.
- amphibole-ferrohastingsite: pleochroic olive green to deep blue green, very small optic angle. 15%
- garnet: grossular-andradite, pale pink, high relief, slightly anisotropic. Euhedral-subhedral, crystals up to 1mm across. 15%.
- ?ilvaite: pleochroic, brown to dark brown-blue, straight extinction, 90° cleavage. 8%.

Minor Minerals:

- magnetite: concentrated in amphibole/garnet zone, 3-4%.

Amphibole, garnet, ?ilvaite and magnetite make up the main portion of the skarn. Amphibole, garnet and magnetite also occur along the fractures which cross-cut the epidote vein. Amphibole is probably retrograde after pyroxene; however, no primary pyroxene was observed.

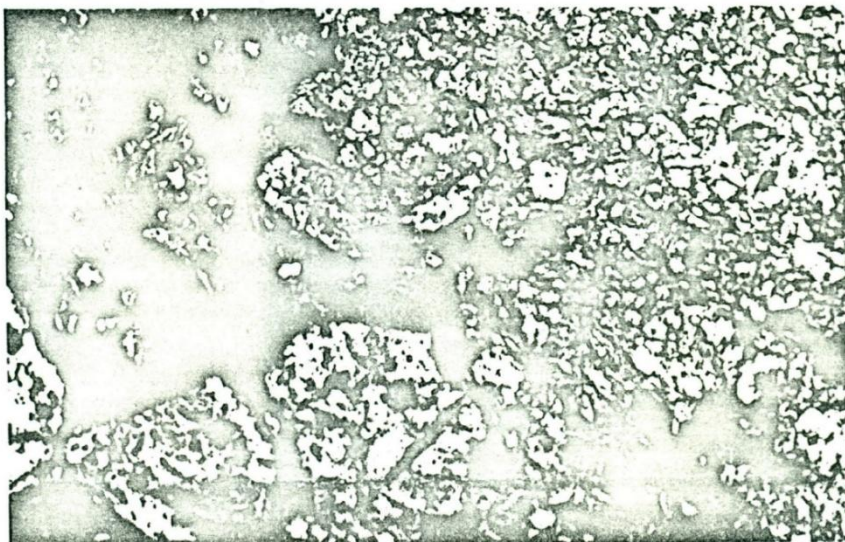


Figure 8. Epidote vein in upper right-hand corner, showing diffuse contact with garnet, amphibole, magnetite zone. Plane light, photo 4mm across.

156 – calcic magnetite skarn

Hand Specimen

Pale green carbonate rock with randomly oriented amphibole crystals. Crudely layered with ferruginous zone, carbonate, amphibole, carbonate. Fe rich zone partially oxidized. Amphibole most abundant near Fe zone.

Thin Section

Major Minerals:

- calcite: anomalous interference colours, interlocking anhedral grains-matrix, 40%.
- amphibole-ferrohastingsite: pleochroic pale yellow green to deep blue green, 10-15° extinction, very small optic angle, -2ve. Grains euhedral to subhedral, 2-5mm long. 30%. See Figure 9.
- garnet-grossular-andradite: pale pink, anisotropic, crystals 1-2mm. 8%.

Minor Minerals:

- ?epidote: high relief and birefringence, as inclusions in garnet and amphibole, along fractures, 1%.
- quartz: anhedral grains, within amphibole, tc. <1%.
- carbonate: trace.
- pyrite (?pyrrhotite) : concentrated in layer, thin lines parallel to crude layering. 3%, see Figure 10.
- magnetite: concentrated in Fe rich layer and disseminated, 2%.

Garnet and epidote appear to be prograde and are followed by ?retrograde calcite. Amphibole and quartz are retrograde, with the large amphibole crystals growing in the calcite matrix. Pyrrhotite and magnetite overprint amphibole.

Difficult to uphold: The epidote granules occur within the carbonate mosaic and so probably formed with the carbonate. The amphibole is corroded by the carbonated and may be coeval with the garnet.

See Figure 9 and 10.

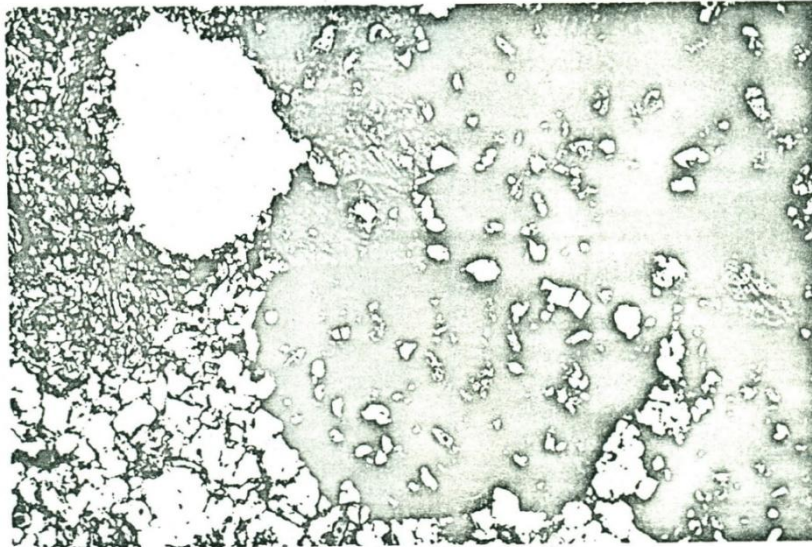


Figure 9. Large amphibole crystals in calcite matrix, with numerous epidote and quartz inclusions. Photo 4mm across.

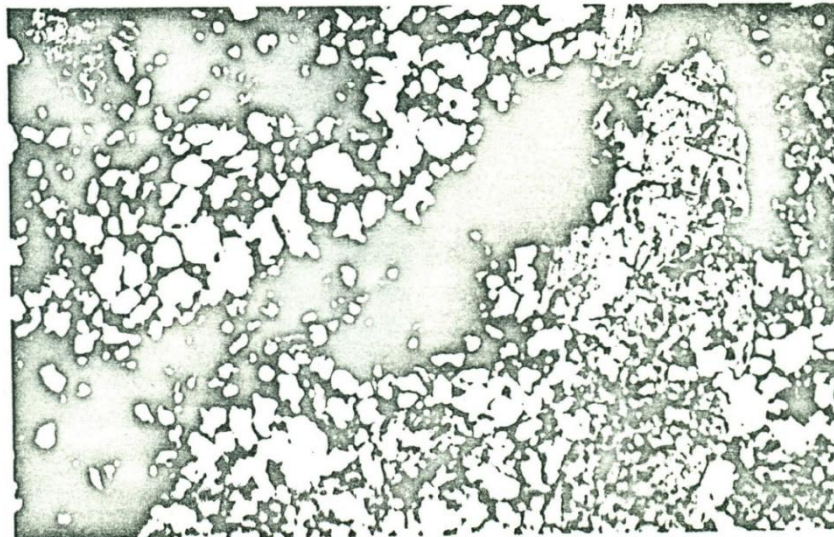


Figure 10. Pyrrhotite and magnetite cross-cutting amphibole. Photo 4mm across.

APPENDIX 6

Geological reports on the geotraverses from north to south

English translation by Stalyn Paucar (2026)

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No. 0265

QUITO, JANUARY 30, 1987

TO : GERENTE TÉCNICO

FROM : ING. RAMIRO BERMÚDEZ and DR. MARTIN LITHERLAND

SUBJECT : Technical Report of the commission carried out to Ibarra-Tulcán from November 19 to December 5, 1986.

SUMMARY:

The Cordillera Real Geological Research Project, which is being carried out with the technical assistance of the British Mission, conducted this field commission in order to continue the traverses established in the annual programming of activities. To this end, surveys were conducted in the Chota Valley sector, where metamorphic rocks of the Ambuquí Fm. outcrop. Additionally, the El Carmelo-Sta. Bárbara-El Calvario-San Francisco (El Playón) zone and the Santa Bárbara-Sibundoy-El Higuerón-La Bonita traverse (with an approximate distance of ± 25 km) were studied.

The rocks studied mostly correspond to: orthogneiss, paragneiss, pelitic and graphitic greenschists, metapsammitic quartzites, and metalavas. Heavy sediment samples (12) and fluvial samples (15) were taken from the main rivers and streams, collecting approximately 50 samples for petrographic study. Regarding economic geology, the sectors present very few interesting prospects.

1. INTRODUCTION

1.1 Objective

Through the various programmed surveys, to continue the study of the metamorphic and igneous rocks of the Cordillera Real.

1.2. Assigned personnel

Brigade No. 1, comprised of:

Ing. Ramiro Bermúdez	(INEMIN)
Dr. Martin Litherland	(BGS/ODA)
Sr. Luis Acosta	(INEMIN/Driver)

A Jeep Land Rover AT-0068, belonging to the mission, was used for transport.

1.3 Geographic aspects

The area studied during this commission is located approximately 160 to 200 km north of the capital, in the provinces of Imbabura, Carchi, and Napo. It covers two sectors:

- (a) Valle del Chota, and
- (b) Tulcán-La Bonita

Bounded by the following coordinates:

(a)	Latitude	0°30'	-	0°15'	S
	Longitude	78°01'	-	77°45'	W
(b)	Latitude	0°40'	-	0°25'	S
	Longitude	77°40'	-	77°29'	W

1.4 Climate and vegetation

Parameters that are directly related to the elevations of the investigated sectors.

Elevations in the area fluctuate between 1800 mamsl (meters above mean sea level) and 3800 mamsl. Located here are Ibarra ($\pm$ 2250 mamsl) and the Chota Valley ($\pm$ 1750 mamsl), which have a subtropical climate; Tulcán ($\pm$ 2950 mamsl), the northernmost city in the country; and El Carmelo ($\pm$ 3800 mamsl) with climates varying from Andean Temperate to Sub-Andean Cold.

Both the high zones and the lowlands are fertile, characterized by crops of corn, barley, wheat, and potatoes; and sugar cane, peanuts, and coffee in the subtropical zones.

1.5 Hydrography

The main hydrographic axes in each of the zones are:



- (a) The Chota River, which for the most part flows through the valley that bears its name; in its upper and middle course, its waters are swelled by the Pisque and Blanco rivers, subsequently taking the name Mataquí River, which together with the Escudilla River forms the Caldera River; in the Juncal sector, it takes the name Chota.
- (b) The Chingual River, which flows in a West-East and North-South direction, constitutes the main river of the zone (El Playón-La Bonita), and additionally serves as the border limit between Ecuador and Colombia.

1.6 Population

The inhabitants of these areas are engaged in agricultural and livestock activities, and the exploitation of timber, especially in the sector comprised between La Bonita and Sibundoy.

1.7 Roadways

The North Pan-American Highway (Quito-Ibarra-Tulcán) constitutes the link to the study area ($\pm$ 230 km/four and a half hours). Access to the Chota Valley is via the North Pan-American and then using second and third-order roads: Ibarra-Ambuquí-El Juncal-Pimampiro-San Francisco de la Caldera-San Rafael-Monte Olivo.

Toward the El Playón-La Bonita zone, first, second, and third-order roads are used: Ibarra-Tulcán-El Carmelo-Santa Bárbara-Sibundoy. Additionally, the Sibundoy (Las Ollas)-La Bonita section ($\pm$ 25 km) is travelled via bridle path (on foot or using mules).

1.8 Land use

Because a high percentage of the investigated areas are covered by thick mantles of volcanic products (ash, lapilli, pumice), which has contributed in part to soils rich in organic matter being used for agricultural and livestock activities, as follows:

In the Chota Valley, there are extensive areas dedicated to the cultivation of sugar cane, peanuts, coffee, cotton, etc.

In the northern zone, the areas are dedicated to the cultivation of potatoes, corn, barley, etc.

1.9 Industries

Agricultural, livestock, and forestry resources constitute the main sources of development on a minor or major scale for the investigated zones. It is important to continue with the construction of the Santa Bárbara-La Bonita road ($\pm$ 35 km), which would benefit the development of the area.

Tourism, especially in the Ibarra-Chota Valley zone, constitutes another source of income due to the climatic conditions.

1.10 Previous works

- San Gabriel geological sheet, scale 1:100000, 1986, DGGM, Quito.
- Ibarra geological sheet, scale 1:100000, 1980, DGGM, Quito.
- National Geological Map, scale 1:1000000, 1982, DGGM, Quito.
- Herbert (1983)
- Feininger (1982)

1.11 Work methodology

The following cartographic bases were used:

- Ibarra topographical sheet, scale 1:50000, edited by the IGM, and the following planimetric sheets, 1:50000; Pimampiro (42), Mariano Acosta (53), Huaca (34), and La Bonita (43), prepared by the IGM for the Population and Housing Census of November 1973.
- Aerial photographs covering the zone (Tulcán-La Bonita), scale 1:60000, taken in the years 1978-1979, acquired from the IGM.

The following methodology was employed:

- “In situ” geological observations
- Study of present structures
- Collection of samples for petrographic study (84)
- Heavy sediment sampling (12) and fluvial sampling (15)

1.11 Geomorphology

The geomorphology of the investigated area is related to the elevations, with two zones clearly standing out:

- One with gentle slopes with elevations between 1700 to 2250 mamsl, where the Chota Valley and the La Bonita sector are located.
- And the other with steep and very rugged slopes with elevations of up to 3000 mamsl: El Carmelo-Santa Bárbara.



2. LITHOLOGY

2.1 Introduction

The Ambuquí-Monte Olivo and El Playón-La Bonita geotraverses do not form a continuous line, but there is evidence that they form a complete traverse along the Andean strike of this sector of the Cordillera Real. That is to say, the rocks - pelitic schists followed by semipelitic gneisses - from the eastern end of the Ambuquí-Monte Olivo section form the western sequence of the Playón-La Bonita section. Thus, in this description, we will treat it as an Ambuquí-La Bonita geotraverse, addressing the units of the Metamorphic Complex from the east.

2.2 Ambuquí zone

The flanks of the Ambuquí Valley are composed of rocks from the Metamorphic Complex. The eastern side is formed by an elongated N-S hill of these rocks, which extends to the Chota River to the north. Sedimentary and volcanic rocks of Cenozoic age outcrop on all sides of this hill, which can be interpreted as a Cenozoic anticlinal axis. Windows of the Metamorphic Complex are found at lower levels on the western flank of the Ambuquí Valley and in the Cachiycu Valley further west.

In the Cachiycu Valley, the westernmost outcrops of the Metamorphic Complex consist of pale and dark fine-grained quartzites intercalated with sericite phyllite and siliceous graphitic phyllites. The outcrops are affected by brittle-motion faults.

Through the Ambuquí zone, the metamorphic sequence is exposed on the Pan-American Highway. To the west, the rocks are metasedimentary with a black appearance, and to the east, they are metavolcanics with a green appearance. The metasedimentary sequence is semipelitic with siliceous graphitic phyllites intercalated with dark quartzites, containing some rounded blue-grey quartz clasts; dark metachert; and siliceous phyllites. Quartz veins are prominent along the first cleavage.

The contact between the metasedimentary and metavolcanic sectors is exposed at the southern hill of Carpuela. It is tectonic and subvertical, followed to the west by 8 m of black phyllite and then by 15 m of dark metachert. Near the contact, and part of the sequence of black phyllites, there are fine siliceous rock bands of pale green colour with cubic hematite crystals interpreted as pyrite pseudomorphs. There are blocks of vein calcite probably derived from the green metavolcanics.

The volcanic sequence is well-exposed on the highway in front of Carpuela. It comprises grey-green schists of the metabasite type (Salazar et al., 1978). There are loose blocks where the igneous texture is better preserved. Small calcite veins were noted.

South of the highway through the Ambuquí Valley, it can be determined that the strike of the contact follows the second cleavage to the SSW and then to the SSE.

2.3 Pimampiro, Monte Olivo and Sigsigpamba zone

In this sector, the metamorphic units have an approximately NE strike, and although there are many structural complications due to outcrops, a brief mapping is sufficient to determine five lithological belts in this sector, which run in a SE direction: the Pimampiro meta-intrusive, the metapsammitic belt, the greenschist belt, the pelitic schist belt, and the semipelitic gneiss belt.

2.3.1 The Pimampiro meta-intrusive: It outcrops along the road to Monte Olivo and the road to Sigsigpamba, and we have also noted it in altered form in the Chuga area within the Escudilla and Mataquí rivers.

The rock is an orthogneiss with a tectonic foliation that corresponds to the second foliation in the schists to the SE. The quartz-feldspathic matrix is coarse-grained. Hornblende crystals are prominent, most of them oriented by the foliation, reaching 3 cm in length in the outcrop on the road to Monte Olivo.

Biotite and muscovite are also present. The sample from the Monte Olivo road has muscovite/K-feldspar lenses separated from the hornblende megacrysts by quartz-rich zones.

There are dark, fine-to-medium-grained “xenoliths” of metadiorite composition, which contain less concentrated hornblende megacrysts.

2.3.2 The psammitic belt: Is the most tentative, based on outcrops on the road to Monte Olivo and SE of Chuga. The rocks comprise quartz schists (feldspathic?), ferruginous quartzites, and biotite metapsammites, with bands of metavolcanic greenschist from 5 cm to 2 m thick.

2.3.3 The greenschist belt: Structurally, it is above the metapsammitic belt along the road to Monte Olivo, where there is a transitional contact. The belt can be followed to the road to Sigsigpamba, where there are intercalations with pelitic schists.

The greenschists vary from fine-grained types to medium-to-coarse-grained rocks with gneiss-type banding with segregations of quartz-feldspathic material. This change is well-developed in an Eastward direction along the road to Monte Olivo. The coarser-grained types contain coloured quartz (amethystine type), sulphides, and hematite. There are intercalations of pale grey-green, fine-grained quartzite.

2.3.4 Concordant intrusions in the greenschist belt: It appears that these are restricted to the greenschist belt and are prominent along the roads to Monte Olivo and Sigsigpamba. They consist of granitic, aplogranitic, and microfeldspathic intrusives of fine to medium grain, from 5 to 40 m thick. Generally, they are tectonically foliated parallel to the schistosity of the surrounding schists. In many cases, the samples contain a red-coloured clay alteration mineral.



2.3.5 The pelitic schist belt: Along the road to Monte Olivo, the outcrops comprise muscovite schists, $\pm$ garnet $\pm$ graphite $\pm$ chloritoid $\pm$ feldspar, with intercalations of pale grey or medium grey orthoquartzite. Along the road to Sigsigpamba, muscovite and garnet schists dominate the belt. There are also schists with fuchsite, graphitic schists; metapsammities with garnet and chloritoid; semipelitic schists with kyanite in veins; and light and dark coloured fine-grained quartzite.

2.3.6 The semipelitic gneiss belt: It outcrops around Sigsigpamba, and there are plenty of boulders upstream from Monte Olivo to indicate its extension to the East. The rocks show muscovite and garnet gneiss, and muscovite schists with garnets up to 2 cm in diameter.

2.3.7 Exotic boulders: That is, lithologies that do not outcrop in the zone, are as follows:

- (a) Quebrada Guambi: biotitic granitoid gneiss (25% of boulders); dolerite-gabbro (one block).
- (b) Río Blanco (bridge): biotitic granite (60%) with euhedral (hexagonal) biotite up to 2 cm in diameter; pegmatite (some blocks) probably associated with the granite.
- (c) Río Sigsigpamba: some granite blocks.
- (d) Río Verde: some amphibolite blocks (garnetiferous metagabbro).

2.4 El Playón-La Bonita section

2.4.1 Río Minas pelitic schist belt: These outcrop along the road at a single site between El Playón and the Río Minas. They are altered pelitic schists. In the Río Minas, there are blocks of pelitic schists and a block of ultramafic tremolitic schist.

2.4.2 El Playón paragneiss belt: It does not outcrop in situ, but the southern rivers are dominated by boulders of these lithologies of the medium-grained muscovite-biotite paragneiss type. There are also blocks of muscovite and chloritoid schists and quartzites, and in two rivers there are some blocks of gneiss (with quartz veins) of the dark-coloured, medium-grained quartz-feldspathic granoblastic type. There are also some blocks of massive basic metalava of a dark grey-green colour.

2.4.3 Sacha orthogneiss belt: It outcrops along the Santa Bárbara-El Playón road; the dominant rock is a medium-grained biotitic orthogneiss (metagranite) with a development of K-feldspar porphyroblasts, which do not exceed 1 cm in length due to the tectonic foliation. The lithology is quite homogeneous, but in boulders, deformed mafic xenoliths and bands richer in biotite are noted. There are also blocks of biotitic paragneiss and granitoid hornblende orthogneiss, in which there are cases of small pegmatitic veins where the hornblende forms megacrysts up to 2 cm long.

2.4.4 Santa Bárbara paragneissic belt: It outcrops through the Santa Bárbara zone and along the road to the SE. The outcrops and boulders indicate that in this belt, paragneiss predominates over the orthogneiss component.

In the creeks to the West of Santa Bárbara, there is a mixture of in situ lithologies: banded biotitic paragneiss with K-feldspar porphyroblasts up to 1 cm long along the foliation; bands of biotitic schist; and medium-to-coarse-grained biotitic orthogneiss (metagranite) similar to that of the Chingual belt. Further to the SE, there are outcrops of fine-to-medium-grained biotite-muscovite paragneiss. Also, in boulders, there are psammitic biotitic paragneiss; xenolithic biotitic tonalitic orthogneiss; hornblende orthogneiss and amphibolitic gneiss.

2.4.5 Chingual orthogneiss belt: This is the most proven of all the belts in the El Playón-La Bonita section due to the excellence of the outcrops along the road.

The outcrops to the North indicate a medium-grained orthogneiss, or an intercalation of fine-to-medium-grained bands with medium-to-coarse-grained ones. Further south, outcrops of coarse-grained white orthogneiss follow, with biotitic porphyroblasts up to 1.5 cm long due to the tectonic foliation. This lithology is characteristic of the belt. It is very homogeneous with little indication of mafic xenoliths and biotitic bands. There is an outcrop where porphyroblastic muscovite forms with biotite. However, in boulders, there are less deformed analogues with metatonalite/metadiorite xenoliths, and some xenoliths have granitic veins. In places, the metagranite contains epidotized plagioclase, especially along joints (diaclasses).

The SE contact of this orthogneiss belt is marked by a zone of about 100 m which begins with biotite and hornblende orthogneiss and further to the SE contains at least 20 m of coarse-grained “metagabbro” of hornblende/plagioclase composition. This mafic zone was crossed twice and on the map is interpreted as a single band.

A sample from the “metagabbro” zone contains about 70% hornblende in the form of sub-oriented lepidoblastic crystals up to 3 cm long with interstices of plagioclase and a very small pink-red mineral (sphene?).



2.4.6 Sibundoy schist, paragneiss, and intrusive belt: It has a very marked contrast with the Chingual orthogneiss. The predominant lithology is a fine-to-medium-grained schistose muscovite-biotite paragneiss, which is banded in many places. Intercalated with this paragneiss are bands or zones of biotitic schist; fine-grained biotitic metagranites; fine-grained feldspathic schist (?acid metavolcanic); fine white, grey, and dark orthoquartzites; and quartziferous metapsammities. There are also minor zones of medium-grained granitoid gneiss with K-feldspar tablets up to 1 cm long. Further south in the belt toward La Bonita, the phyllitic-type intercalations include fine quartz phyllite; grey graphitic phyllite; psammitic phyllite; muscovite phyllite; and metagraywackes. There are also boulders of quartzitic metaconglomerate with graphitic scales.

In this southern sector of the belt where the phyllites outcrop (above), there are sectors of mylonitized plutons. One is of granitic composition, medium-grained, selectively deformed with zones of augen gneiss; while the other is a biotitic metadiorite/metagabbro of original coarse grain.

Also, in this sector and to the north as far as Sibundoy, there are outcrops of fault quartz rock. In certain places, an association of this rock with mylonite zones can be seen.

2.4.7 La Bonita orthogneiss belt: It outcrops in the vicinity of La Bonita and consists of a coarse-grained, homogeneous metagranite with biotite porphyroblasts, equal in every aspect to the Chingual orthogneiss.

2.4.8 Late minor intrusives: These are prominent in the Chingual and Sibundoy belts. They consist of aplite, granite, porphyry, and lamprophyre. They are more concentrated in the Sibundoy gneiss and schist belt where the granite or porphyry dikes, up to 15 m thick, are concordant with the gneissic foliation and have foliated margins chilled against the gneisses.

3. STRUCTURE AND METAMORPHISM

3.1 Ambuquí zone

The black and green sequences of Ambuquí are of low metamorphic grade and contain two penetrative cleavages (S1 and S2) and other later non-penetrative ones that form vertical or horizontal minor folds. Along the Pan-American highway section, the layers (S0) and the first cleavage (S1) are subparallel. The second deformation (D2) forms the prominent cleavage associated with minor folds with inconsistent plunges due to vertical refolding (D3). In the quartzites and cherts, the D2 folds are of parallel style.

Approaching the contact with the green schists, the D2 folds are tighter, and the contact zone is identified as a subvertical D2 drag zone. D2 fold noses involving So/S1 are truncated along this contact. This tectonic contact can be followed to the south, parallel to the strike of S2.

3.2 Pimampiro-Monte Olivo-Sigsigpamba zone

In this area, the general strike of 60 degrees is an expression of a second schistosity, probably subparallel to So and S1. Deviations from this strike can be attributed to late deformations (D3). An example of this is found on the road to Monte Olivo, where D3 forms a fold of So/S1/S2 plunging to the NE, but without penetrative cleavage.

There are zones where S2 changes dip direction while maintaining a fixed strike. In one case, it can be demonstrated that this phenomenon is a fan-shaped structure.

The tectonic foliation of the Pimampiro orthogneiss can be correlated with the regional S2.

The metamorphism of this sector may reach amphibolite facies. There are gneissic textures, garnet megacrysts, and hornblende recrystallization in the Pimampiro orthogneiss and some amphibolite blocks.

The SE contact of the Pimampiro orthogneiss can be interpreted as a fault subparallel to the regional strike.

3.3 El Playón-La Bonita section

With the exception of the phyllites to the south of the Sibundoy belt (near La Bonita), the metasedimentary rocks (schists and paragneiss) of this section contain two penetrative schistositities. The evidence comes from:

- (a) Penetrative S2 in the schists is axial planar to S1 microfolds.
- (b) In the paragneisses, D2 forms folds (with axial planar S2) that affect the paragneiss banding parallel to quartz veinlets.

However, in the orthogneiss belts, there is only one tectonic foliation, which corresponds to S2 in the metasedimentary rocks.

In the phyllites near La Bonita, there is only one penetrative cleavage, and it is difficult to determine whether it corresponds to S1 or S2 of the sequence to the North, and/or the mylonitic foliation in nearby plutons. One possibility is that regional S2 corresponds to S1 of the phyllites and the mylonitic structure.



The structure S2 dominates the section. It is normally NE-striking and subvertical. Porphyroblastic metamorphic minerals (biotite, K-feldspar, hornblende) are elongated/lineated along it. There are certain outcrops, which do not appear to be collapsed, where S2 is subhorizontal, which can be attributed to a later deformation phase. Evidence of later deformation is also found in the form of horizontal crenulations.

The metamorphism of the El Playón-La Bonita sector can be compared with that of the Pimampiro sector. There is no evidence of higher-grade metamorphism such as migmatitic gneiss belts.

4. CORRELATION AND DISCUSSION

The metamorphic rocks of Ambuquí and Pimampiro/Monte Olivo/Sigsigpamba are designated as the Ambuquí Group (Baldock, 1982) and correlated with Palaeozoic metamorphic rocks in Colombia. According to the studies of this project, the Ambuquí rocks can be correlated with the Peltetec collision sequence (Alao Valley) of possible Mesozoic age. This correlation is supported by the strike and geographic location (west of the Cordillera Real) and the lithologies. In Ambuquí, the black belt (with chert) and the green belt have the same spatial relationship (green East of black) as in Peltetec; it only lacks the serpentinites and spilites (ophiolites) between the belts. This absence can be interpreted by the tectonic contact seen in the field.

In contrast, the schists of Pimampiro/Monte Olivo and Sigsigpamba correspond lithologically to those of Papallacta-Baeza, Río Mulatos, and Baños-Río Topo, for which a Palaeozoic age can be proposed (without radiometric evidence). The “Baños front”, which divides this “metamorphic core” from the Mesozoic collision sequence, would have to pass between Ambuquí and Pimampiro, where there is a major change in strike between the two sequences.

If the two sequences have different ages and geological histories, then the structural history from Ambuquí to Pimampiro could not be correlated.

The El Playón-La Bonita sequence can be interpreted as part of the same orogenic belt as the Pimampiro/Monte Olivo/Sigsigpamba schists, without the need to divide them into two ages: Ambuquí and Cofanes (Precambrian) Groups (Baldock, 1982). Thus, the paragneisses and schists form the host rocks of syn-tectonic (syn-D2) granitic batholiths manifested as orthogneisses. Based on this setting, it is possible that the batholiths form D2 antiforms and the metasediments form D2 synforms. The Chingual batholith has a finer-grained NW contact zone and a hornblendic SE contact zone, which can be interpreted as an assimilation zone or an older mafic intrusive.

Many theories can be attributed to the presence of a single cleavage in the phyllites near La Bonita.

5. ECONOMIC GEOLOGY

5.1 Metallic minerals

5.1.1 Copper: Small copper mineralizations altering to malachite have been noted in a block of the Pimampiro orthogneiss.

5.1.2 Chromium: The mineral fuchsite (chrome-muscovite) is present in semipelitic schists along the road to Sigsigpamba.

5.1.3 Iron and sulphides: Small hematite crystals were noted in pegmatite blocks and in quartz veins associated with galena (5.1.5).

Sulphide concentrations occur in the hornblendic zone of the Chingual orthogneiss contact and in the green schists along the road to Monte Olivo.

5.1.4 Molybdenum: Small flaky crystals of molybdenite, up to 1 cm wide, form with sulphides in laminae less than 1 mm thick within a quartz vein inside the hornblendic zone of the Chingual orthogneiss belt.

5.1.5 Lead: Small galena mineralization is found in a concordant muscovitic granite intrusion within green and pelitic schists along the road to Sigsigpamba. Galena crystals up to 5 mm long were found isolated in quartz veins 2 cm thick. In other 5 cm quartz veins, no galena was present. Hematite also forms in the veins.

5.2 Industrial rocks and non-metallic minerals

5.2.1 Abrasives: Garnet and kyanite are found in the schists, but not in concentrations of economic importance.

5.2. Calcite: There are small calcite veins near the contact with the Ambuquí green schists.

5.2.3 Kaolin: On the road to Monte Olivo, there is a kaolinized zone of a concordant dike within green schists. The dike is of microfeldspathic composition with a low percentage of quartz. It has a thickness of about 40 m with about 20 m of strong kaolinization, and other sectors of lighter kaolinization.

5.2.4 Quartz: Along the road to Sigsigpamba, there is a 3 cm wide quartz vein that is quite pure (milky quartz).



5.2.5 Graphite: The graphite content in the carbonaceous schists and phyllites does not reach economic interest.

5.2.6 Mica: There are muscovite and biotite plates up to 1 cm wide in blocks of pegmatitic material, but they have no economic importance.

5.2.7 Stone: Some of the metagranitoid bodies (orthogneiss) have potential for ornamental stone. The most attractive would be the Pimampiro orthogneiss and the hornblende contact zone of the Chingual belt. In both cases, there are hornblende megacrysts. The extensive Chingual orthogneiss with its biotite megacrysts can also be considered. In a large waterfall outcrop, joints were noted with strikes of 120 degrees and 190 degrees and a distance between joints of 10 to 150 cm.

5.2.8 Gypsum: Near the kaolin deposit (see 5.2.3), there are also signs of gypsum that have no economic importance.

5.3 Unproven local information

On a “rustic” map of the Sigsigpamba Parish, which was shown to us by Sgt. Carlos Arciniegas, the presence of: gold veins (approx. 3900 meters above sea level), a mica mine, cement limestones, mineral waters, and “uranium gas” are indicated; all apparently near San Francisco de Sigsigpamba. There was no time to visit the localities.

6. RECOMMENDATIONS

At the present time, the field mineral indications do not have sufficient interest (quantity and economic environment) to recommend more detailed studies. This first impression could change when the geochemical results are obtained.

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Dr. Martin Litherland

Ing. Ramiro Bermúdez

CORDILLERA REAL PROJECT

ATTACH. Two (2) geological-structural maps
Two (2) location maps of petrographic samples



No. 2658

QUITO, JUNE 17, 1986

TO : GERENTE TÉCNICO

FROM : CORDILLERA REAL PROJECT

SUBJECT : Technical Report of the commission carried out to Papallacta-Baeza from June 2 to 6, 1986

SUMMARY:

The Cordillera Real Geological Research Project, which will be executed with Technical Assistance from the Government of Great Britain, began its field studies with this Commission. The project counted on the collaboration of two professionals working at the Escuela Politécnica Nacional, one of whom (Pablo Duque) had previously conducted studies in this area. Thus, several traverses were made through Papallacta-Cuyuja-Baeza-San Francisco de Borja, also observing rocks belonging to the Abitagua Granite, south of Cosanga. Special attention was given to the rocks belonging to the metamorphic belt, as well as to the structural aspect and the ease of finding mineralizations that could yield positive results (Economic Geology).

1. INTRODUCTION

1.1 Objective

The present Commission, which is the first of its kind, aimed to maintain direct contact with the metamorphic units outcropping in the area; in order to unify criteria regarding nomenclature, description, and work methodology to be used in subsequent sections across the Cordillera Real.

1.2. Assigned personnel

The Commission consisted of the following personnel: Ings. Ramiro Bermúdez and Francisco Viteri, National Counterpart (INEMIN); Drs. Martin Litherland and John Aspden, British Mission (ODA); and Ings. Pablo Duque and Arturo Egüez, Escuela Politécnica Nacional. Jeeps belonging to the Mission were used as the means of transport.

1.3 Geographical aspects

1.3.1 Location: The area subject of this report is located in the northwestern Ecuadorian “Oriente” (Amazon region), approximately 94 km east of the city of Quito. It is bounded by the following coordinates:

Longitude	:	77° 50'	y	78° 10'	W
Latitude	:	00° 28'	y	00° 20'	S

1.3.2 Climate and vegetation: The climate and vegetation are in direct relation to the elevations of the sector. These fluctuate between 3000 meters above sea level (Papallacta) and 1900 meters above sea level (Baeza), with a variation from a temperate to a subtropical climate, with temperatures ranging between approximately 10°C and 15°C. The vegetation is related to the climate; in the temperate zone, there is exuberant non-tropical jungle-type vegetation, and in the subtropical climate, “high jungle” (cloud forest) with large trees exists.

1.3.3 Hydrography: The Papallacta River, which flows from east to southeast, takes this name after the confluence with the Quijos River, constituting the main fluvial axes of the area. These rivers originate in the paramos of Antisana (5705 meters above sea level) and then flow along the northern and eastern flanks of the snow-capped volcano.

The main tributaries of the left bank from west to east are: Chalpi River, Cuyuja River, Victoria River, Jatuntinagua River, Paradalarga River, and Sardinas Chico River. Those of the right bank are: Taminguín River, Blanco River, Quijua River, Huagrayacu River, and Machángara River.

1.3.4 Population: The zone belongs to the Napo Province, Quijos Canton, whose capital is the city of Baeza, encompassing two parishes: Papallacta and San Francisco de Borja. The majority of the population is dedicated to agricultural and livestock labour.

1.3.5 Roadways: The study area has the Quito-Pifo-Papallacta-Baeza-El Chaco highway, which constitutes one of the main penetration routes into the Ecuadorian Oriente. Currently, the Pifo-Papallacta road (40 km) is under construction; with important variations in its layout, it will become a primary highway. Heliports of oil companies exist in Papallacta and Baeza.



1.3.6 Land use: In the area, a high percentage of the land is dedicated to agricultural labour, especially in rural sectors where there is a higher concentration of the economically active population. In sectors where volcanic, metamorphic, or intrusive rocks outcrop, these are used for the maintenance and surfacing of roads.

A small deposit of travertine (2.4 km from Baeza), which is exploited by artisanal methods, is calcined in kilns to obtain quicklime (CaO).

1.3.7 Industries: The livestock and agricultural industries constitute an important source for the development of this sector. Tourism holds a prominent place; in the area, we have the Laguna Papallacta and the thermal water pools, which constitute the main tourist attraction. Additionally, the Antisana Volcano (5705 meters above sea level) can be admired from the highway.

1.4 Previous works

The geology of the Papallacta-Baeza highway has been studied by Colony and Sinclair (1932), Bamba and Herrera (1965), Sauer (1965), Trouw (1976), and Herbert (1977, 1983), who provide summaries of the area.

1.5 Work methodology

- The Papallacta (census) sheets, 1:50000 from the IGM, 1973, and the Baeza (topographic) sheet, 1:10000 (section area), a sheet prepared by INEMIN, 1983, were used.
- Aerial photographs covering the section at 1:40000 and 1:60000 scales.

Thus, the following work methodology was employed:

- “In situ” geological observations.
- Study of the present structures.
- Description of the rocks (macroscopic)
- Collection of petrological samples (30) for analysis.

1.6 Geomorphology

The Papallacta-Baeza section (3) is located in the high zone of the Cordillera Real, with altitudes exceeding 3500 meters above sea level, featuring steep slopes and deep ravines; and another zone with moderate slopes (Cuyuja-Baeza-San Francisco de Borja), which practically constitutes the eastern foothills of the Cordillera.

2. LITHOLOGY

2.1 Introduction

The lithology of the zone comprises metamorphic rocks termed the Metamorphic Complex, non-metamorphosed sedimentary rocks of the Tena Formation (Cretaceous), a subvolcanic intrusion of possible Jurassic age, and a non-metamorphosed volcanic cover of Cenozoic age. There are also recent alluvial deposits which are not indicated on the map.

The Metamorphic Complex, as it has been named here, is a lithological term and includes “semimetamorphic” rocks termed the Margajitas Group in various geological maps of the Sub-Andean belt. According to Feininger (1975) and Trouw (1976), the age of the Complex is Cretaceous, but other authors (Sauer, 1965; Baldock, 1982) designate it as Palaeozoic, with possible Precambrian relicts. The formal establishment of lithostratigraphic units, e.g., as by Trouw (1976) within the Papallacta-Baeza section, is a violation of the rules of lithostratigraphic classification (Hedberg, 1976). Until there are sufficient geological, structural, and geochronological studies to determine a stratigraphic column, informal nomenclature must be used. In the case of the Cordillera Real, the term “Complex” is appropriate for understanding all the metamorphic rocks at the present level of study.

2.2 The metamorphic complex

From Baeza to Papallacta, most of the outcrops along the highway present a semipelitic and metavolcanic appearance of low-grade metamorphism (greenschist facies). In the attached map, they are subdivided by lithological composition with symbols identifying ultrabasic, calcareous, psammitic, pelitic, carbonaceous, calc-magnesian rocks and granitoids with the prefix X (= Metamorphic Complex). Only near Baeza is the original stratification (layering) clearly seen, while sedimentary structures useful for determining the order of deposition are absent.

2.2.1. Ultrabasic rocks: Pablo Duque informed us that there were serpentinite boulders in the Chalpi River. According to Colony and Sinclair (1932), there is a serpentinite outcrop 2 km from Baeza in the Quijos River, but we could not find it, although we saw serpentinite boulders in the same area of the river.

At 7 km east of Papallacta, along the highway, there are boulders from a stream of an ultramafic schist with garnet. We did not have time to look for the serpentinite reported by Bamba and Herrera (1965) to the west of Papallacta.

2.2.2 Calcareous rocks: Prominent metamorphosed fine-grained black limestones are found in the Machángara and Paradalarga rivers, near Baeza. With calcite or quartz veins.



2.2.3 Psammitic rocks: From Papallacta to Baeza, intercalations of white orthoquartzites, quartz-albite schists, and siliceous schists are common within more pelitic rocks of the Complex. However, these bands or laminations do not dominate the total lithology of the outcrop, with the exception of a single one 10 km from Baeza. Between Cuyuja and Papallacta, there are outcrops and boulders of medium to coarse-grained rocks, more granoblastic, which contain blue quartz and some feldspars. The town of Papallacta has good outcrops of this rock where sillimanite has been identified (Pablo Duque).

2.2.4 Carbonaceous rocks: Graphitic schists are common on the road between Cuyuja and Baeza, intercalated with the semipelitic sequence.

2.2.5 Pelitic rocks: These comprise the majority of the section, although there is a variation in quartz content. Near Baeza, there are aluminous phyllites of almost pure muscovite. Towards the west, there are green-grey quartz-chlorite-albite phyllites, which carry very attenuated volcanic clasts along the schistosity. Towards Papallacta, the dominant rocks consist of quartz, albite, muscovite, $\pm$ chlorite, $\pm$ chloritoid, $\pm$ biotite, $\pm$ epidote, $\pm$ sulphides schists; with rare developments of garnet and kyanite. Colours vary from pale grey to pale green; and grain size ranges from fine to medium.

2.2.6 Calco-magnesian rocks: Near Papallacta, there is an outcrop of fine to medium-grained feldspathic amphibolite, with a thickness of no more than three meters. There are also fine-grained amphibolite boulders 7 km from Papallacta. In the Sardinas Chico River, north of Baeza, there are amphibolite boulders with fine and coarse-grained bands of igneous origin.

2.2.7 Granitoid rocks: West of Cuyuja, there are outcrops and boulders of a granitoid-type gneiss, intercalated with more aluminous feldspathic gneisses of the paragneiss type.

2.3 Granitoid intrusives

o the west of the road to Cosanga, south of Baeza, there are hills of an intermediate composition granitoid porphyry with biotite and hornblende. To the southeast, off the map, passing through Cosanga and on the road to Tena, we studied outcrops of the Abitagua Granite: a pale pink, medium-grained granite with white feldspar phenocrysts. Oriented xenoliths of greywacke and limestone exist. The Abitagua granite has K-Ar ages of 178 ± 7 Ma (Hedberg, 1977) and 87 ± 7 Ma (Kennerley, 1980); and by Rb-Sr (three points) of 173 ± 5 Ma (Hall and Calle, 1982), giving a Jurassic age for the granite

2.4 Napo Formation

Along the same road to Cosanga, there are weathered outcrops of dark grey shales with bands of pale quartzite; these are assigned to the Napo Formation.

2.5 Volcanic cover

These rocks of Cenozoic age were noted but not studied. Outcrops are found in the Quijos River near Baeza. Between the mouth of the Huagrayacu River and Cuyuja, volcanic rocks formed the escarpment south of the Quijos-Papallacta River and possibly continue to Papallacta, while the “Metamorphic Complex” outcrops to the north. This distribution differs from the pattern shown on the 1:100000 sheets from INEMIN (unpublished) of Baeza and Píntag.

2.6 Minor intrusions

Quartz veins are located in the schists of the Metamorphic Complex. They belong to four syn-tectonic periods (D1, D2, D3) and late fractures. That is to say, there are veins along S1, S2, S3, and cutting across S3. Those along S3 reach 50 cm in thickness and contain, in some places, megacrysts of blue kyanite and chloritoid. There are boulders of vein quartz up to one meter wide. Pyrite is common in the quartz veins. Three kilometres west of Baeza, there are pegmatitic veinlets along S1 and S2, as well as calcite veinlets. In the limestones near Baeza, there are quartz and calcite veins.

3. STRUCTURE

3.1 Introduction

Four phases of deformation, D1 to D4, have been identified in the “Metamorphic Complex”, followed by faulting. D1 to D3 formed penetrative foliations. The structural elements of each deformation phase are S1 to S3 (schistosity/foliation) plotted on the map, accompanied by L1 to L3 (lineations).

3.2 D1 deformation

The S1 cleavage is clearly noted around Baeza, where S2 is only a crenulation and S3 is absent. Relations with primary stratification (layering) indicate there are no previous deformations. S1 is penetrative and defined by the elongation of quartz, the alignment of micas, and quartz veins. D1 folds have not been noted, although in Papallacta there is evidence of D1/D2 interference structures.

3.3 D2 deformation

Near Baeza, S2 forms a prominent vertical crenulation cleavage, axial planar to folds with a sense of virgation towards the east. Towards the west, where the highway crosses the Quijos River, there are blocks where S2 planes are closer together, leaving S1 as micro-crenulations. Along the rest of the highway to Papallacta, S2 is essentially penetrative, although in some places micro-corrugation of S1 is noted. Aside from the Baeza area, D2 folds on a larger scale than micro-corrugations are scarce.



3.4 D3 deformation

At the point where S2 forms a penetrative foliation (see the structural diagrams on the map), S3 enters the tectonic sequence as a crenulation cleavage dipping to the east with gentle folds of two meters in amplitude, with gentle plunges (L3). Near the junction of the Quijos and Papallacta rivers, there is a very clear transition from S3 (crenulation) to S3 (penetrative), where S2 is folded in a tighter manner. This is followed by the “flat zone” of penetrative S3 with gentle dips, followed by a steeper zone starting at Cuyuja. The strike of S3 in this last zone is trans-Andean (NW-SE), with a dip of 45° to the SW. Along the Chalpi River to Papallacta, it seems that S3 returns to a crenulation cleavage dipping west and with folds showing a sense of virgation towards the east.

3.5 D4 deformation

This phase forms gentle folds with slight plunges of more than 100 m in amplitude, folding S3 through the “flat zone” with moderate NE-SW striking axes. No effects of D4 have been noted in the steeper S3 zone.

3.6 Faults and joints

A fault zone was noted: it consists of a breach of disoriented graphitic schist blocks in a graphite-quartz matrix. The other faults on the map are inferred. Joints are prominent in some places; slickensides were also observed.

4. METAMORPHISM

According to Pablo Duque, the metamorphism of the “Metamorphic Complex” reaches the top of the greenschist facies, with the exception of the Papallacta rocks which contain sillimanite from high-grade regional metamorphism. Herbert (1983) and Trouw (1976) also place the rocks in the greenschist facies, and the assemblage: quartz + muscovite + albite ± chlorite ± chloritoid is the most typical of the traverse. The amphibolites we found contain hornblende, but probably from the retrogression of igneous pyroxene.

The three penetrative schistositys demonstrate the superposition of metamorphic stages with reference to micaceous minerals. The latest kyanite crystals are prominent in quartz veins along the penetrative S3. The gneisses (ortho- and para-) probably represent the arrival of the amphibolite facies.

5. CORRELATION

It would be very premature to correlate the rocks of the Metamorphic Complex because there are no data to justify it. However, it is worth noting that the “change” west of Baeza from rocks called the Margajitas Group to those of the Metamorphic Complex is not very clear (the limestones disappear). In the Metamorphic Complex, there are two refoliations that destroy the evidence of stratification, and this may be the greatest difference.

There is no correlation with the tectonic scheme of Trouw (1976), who noted the penetrative foliation as S₁, without realizing that this foliation changes from S₁ to S₂ and to S₃ along the highway.

6. DISCUSSION

The Metamorphic Complex is an original semipelitic/volcanic sequence without useful index horizons for correlation and the construction of a stratigraphic column. Furthermore, for the most part, the original stratification was destroyed by tectonic-metamorphic refoliations. Without stratigraphic control, we attempt to obtain tectonic control of four phases of deformation. This demonstrates (see map) the existence of a horizontal tectonic regime (D₃) folded by D₄ in the form of a possible antiform. There is the possibility that D₃ was a phase of overthrusting or flow where there is a penetrative foliation followed by higher levels of crenulation structures.

The regional importance of this horizontal D₃ structure can be defined by the other sections of the Cordillera Real that this Project will undertake.

The identified “orogenic” tectonic sequence still has no age. If the Margajitas Group exists near Baeza, with a Cretaceous age, it is possible to interpret a superimposed tectonic sequence for the S₁ of this zone, supporting Feininger’s (1975) theory of a late or post-Cretaceous orogeny.

7. ECONOMIC GEOLOGY

7.1 Metallic minerals

7.1.1 Gold: there are recent alluvial gold workings in the Sardinas Chico River.

7.1.2 Copper: a small block of vein quartz in the Sardinas Chico River shows azurite.

7.1.3 Iron: the same block (7.1.2) shows hematite. Sulphides dominated by pyrite are located in the Metamorphic Complex and form euhedral crystals up to one centimetre wide, especially in cavities associated with quartz veins.

7.1.4 Lead: there is an occurrence of lead in the Sardinas Chico River area on the Metallic Minerals index map (INEMIN, 1985). A sample from Colony and Sinclair (1932), from a schist (17 km east of Papallacta), contains sulphides with galena.



7.2 Industrial rocks and non-metallic minerals

7.2.1 Graphite: There are two locations on the map where graphitic schist dominates the assemblage. However, neither contains graphitic content of economic interest.

7.2.2 Kyanite: The kyanite is better developed in quartz veins with crystals up to 5 cm in length, but the kyanite is low in abundance.

7.2.3 Travertine: The occurrence on the map consists of an outcrop of the Metamorphic Complex that is completely carbonatized, five meters thick, and preserves original fold structures. There is a kiln nearby for processing the travertine.

7.3 Construction materials

There is an abundance of materials for use as riprap and aggregate. No materials suitable for ornamental stone were observed.

7.4 Hot springs

The Papallacta thermal waters were not visited.

8. CONCLUSIONS AND RECOMMENDATIONS

The study has directed us toward a type section of the Metamorphic Complex, demonstrating the difficulties of stratigraphic analysis and the structural complexity. A new tectonic interpretation has been presented, involving possibilities of regional overthrusting.

In subsequent commissions, a Project team must collect geochemical samples along the Papallacta-Baeza highway, study another cross-section at the Margajitas/"Metamorphic Complex" contact, and investigate the economic potential of this zone, which appears to be very productive.

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NOTE: Structural geological map attached

CORDILLERA REAL PROJECT

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INEMIN



No. 5045

QUITO, NOVEMBER 14, 1986

TO : GERENTE TÉCNICO

FROM : ING. RAMIRO BERMÚDEZ and DR. MARTIN LITHERLAND

SUBJECT : Technical Report of the commission carried out for Section 4:
Salcedo-Tena, from October 6 to 22, 1986.

SUMMARY:

The Cordillera Real Project, carried out with the technical cooperation of the British Mission, conducted this commission to continue the cross-sections established in the annual activity schedule; thus, Section 4, belonging to the Salcedo-Tena geotraverse, was completed in its entirety.

The objective of the commission was to study the metamorphic and igneous rocks of this sector of the Cordillera through the Salcedo-Tena section (± 40 km), regarding both their geological-structural aspects and an initial exploration of the potential economic value of these rocks. In general, the rocks consist of schists, gneiss, lavas, metalavas, carbonate rocks, and intrusive rocks (Abitagua Granite), etc. It should be noted that the majority belong to large boulders located in the beds of the Anatenorio and Mulatos rivers and their tributaries; in situ outcrops were located only sporadically.

It is worth noting that this crossing- with a total distance of ± 50 km to Shandía - was difficult and laborious; it took 13 days, but thanks to the people who accompanied us, we managed to overcome the obstacles encountered along the traverse. Their daily wages were fully earned, and for Brigade No. 1, it constituted a "trial by fire", from which we emerged successful despite the logistical limitations we faced.

Approximately ± 50 samples were collected for petrographic study and 22 for geochemistry, corresponding to stream sediments (12) and heavy minerals (10).

1. INTRODUCTION

1.1 Objectives

Through the scheduled cross-sections, continue the study of the metamorphic, semi-metamorphic (?), and igneous rocks of the Cordillera Real.

1.2. Assigned personnel

Brigade No. 1, composed of:

Ing. Ramiro Bermúdez A.	(INEMIN)
Dr. Martin Litherland	(ODA)
Sr. Alfonso Vaca	(Vehicle driving and maintenance/INEMIN)

A Jeep Land Rover AT-0068, belonging to the mission, was used as transport.

1.3 Geographical aspects

1.3.1 Location: Section 4 Salcedo-Tena is located southeast of the capital, approximately 90 km (Salcedo); from here, 60 km to the east is the Las Carmelas sector (2850 mamsl) where the Salcedo-Pano highway ends, between the provinces of Cotopaxi and Napo. It is bounded by the following coordinates:

Longitude	:	78° 18'	y	78° 02'	W
Latitude	:	00° 59'	y	01° 05'	S

1.3.2 Climate and vegetation: Parameters that are directly related to the elevations of the area, as well as the morphological configuration which also influences the climate and vegetation. Thus: the region between Las Carmelas (2850 mamsl) and the Tambo de los Leones sector (3150 mamsl) has a temperate Andean to cold climate, with precipitation and winds. The foothills of the Cordillera: Zapalá River (2330 mamsl) to the Katachi River (920 mamsl) have a temperate subtropical climate.

The vegetation is closely related to the climate: in the high zones, there are *pajonales* (tussock grasslands) and *chaparros* (scrubland); in the lower zones, there are crops of potatoes, barley, etc. The subtropical zone is covered by large forests and a variety of subtropical flora.

1.5 Hydrography

The main hydrographic axes are the Anatenorio and Mulatos rivers.



The Anatenorio River, which originates in the heights of the Cordillera Real at ± 3800 mamsl (Uspasacha Lakes sector, Antejos, etc.), flows in an east-northeast direction, receiving the Langoa River as a tributary, which flows in an east-southeast direction to form the Mulatos River. For the most part, the latter is a torrential and very rugged river, receiving the following rivers as tributaries: on the left bank: Zapalá, Tigre, Niágara Chico, Niágara Grande, Negro, Katachi; and on the right bank, the Yarapo River and, further downstream, the Verdeyacu River, which together go on to form the Jatunyacu River.

1.3.4 Population: The inhabitants of the Tambo de los Leones-Las Carmelas sector, who are few (settlers), are dedicated to agriculture and livestock, and sporadically to work for the Salcedo-Napo Cooperative (local road construction, vegetation clearing, etc.). Between km-60 and the INECEL Cable, apart from wild animals, there are no settlers in the area; therefore, the section is completely isolated, and for the most part, we were accompanied only by the sound of the jungle and the Mulatos River.

1.3.5 Roadways: The Pan-American South (primary road) Quito-Salcedo, 120 km, constitutes the link to the area; from there, it is 60 km to the Las Carmelas sector, where this secondary road ends. It is mostly ballasted and is in fair condition, especially in the páramo zone.

From here, for the crossing from km-60 to the INECEL Cable, there is a trail that is not “clear” in its first sections; most of the crossing was carried out through the riverbed of the Mulatos River.

Crossing the Jatunyacu River, one takes the El Pano-Tena road. The return to the capital was made via the Tena-Baeza-Papallacta-Quito highway; a route widely used for entry and exit to/from the Oriente (Amazon region).

1.3.6 Land use: A percentage of the soils are dedicated to agricultural and livestock activities (km-60, Las Carmelas). The rest remains virgin; furthermore, the majority is affected by geodynamic phenomena.

1.3.7 Industries: Due to the lack of access roads, industries are totally absent from this sector (km-60 to the INECEL Cable).

1.4 Previous works

- Sauer W. (1965) gave a description of the geology of: Mulatos-Langoa and Zapalá rivers.
- Guzmán J. and León J. (1982) Geological Map “San José de Poaló”. Unpublished.

1.5 Work methodology

The following cartographic bases were used:

- Topographic map of Laguna de Antejos, scale 1:50000, edited by the IGM.
- Planimetric maps of Chalupas (152) and Río Mulatos (160), scale 1:50000, prepared by the IGM for the Population and Housing Census of November 1973.
- Aerial photographs covering the area, scales 1:40000 and 1:60000.

The following methodology was used:

- Geological observations
- Structural study
- Sample collection for petrologic study (± 50)
- Sampling of heavy minerals (10) and stream sediments (12)

1.6 Geomorphology

The studied area is characterized by being a zone with steep slopes and deep gullies that make ascent and descent difficult (Gallourco, 2800 mamsl); moderate to gentle slopes (INECEL Cable, 920 mamsl - Shandía). Because 90% of the crossing was carried out along the riverbed of the Mulatos River, the difficulties and the geomorphology of the area became more apparent day by day, with falls, canyons, and cliffs that drained our time and physical energy.

2. GEOLOGY

2.1 Introduction

The Mulatos River appears typical of the rivers that descend from the Cordillera Real to the Oriente (Amazon basin), both in terms of physical and geological difficulties. That is to say, the geological studies include the location and analysis of outcrops in situ or near-situ (visibly derived from landslides on the flanks), and studies of exotic boulders. The exotic boulders comprise lithologies that do not outcrop along the traverse, and it is an important duty for the field geologist to search for the source of these blocks-that is, to examine the boulders at the confluences to identify where the exotic blocks originate.

In this description of the geology of the Mulatos River, the section is divided between the Metamorphic Complex and the non-Metamorphic Complex to the west and east of the traverse, respectively. The metamorphic and non-metamorphic exotic boulders also deserve separate descriptions.

This geological description was conducted without the support of thin-section analysis (petrography).



2.2 The Metamorphic Complex in situ

2.2.1 The Río Anatenorio zone: This comprises the outcrops of the Metamorphic Complex along the path beside the Anatenorio River until its junction with the Langoa River to form the Mulatos River. In this area, the Metamorphic Complex outcrops as a window at the bottom of the valley, beneath Cenozoic lavas.

The metamorphic rocks include fine banded quartzites, glassy (especially near the junction with the Langoa River); coarse-grained quartz schists, glassy grey garnetiferous quartzites, and metapsammitic rocks. There are also pelitic schists with muscovite and biotite ($\pm$ garnet, $\pm$ chloritoid); graphitic schists, and greenschists (metatuffs?) (quartz-chlorite-albite-chloritoid-epidote). There are more massive green-grey metamorphic rocks of fine to medium grain containing quartz, feldspar, chlorite, biotite, and garnet, which are likely derived from basic to intermediate intrusives with pre- or syn-tectonic composition. Small bands of amphibolite intercalated with quartzite and quartz-garnet schists have also been observed. This association indicates a sedimentary origin (para-amphibolites). The gneisses in this sector are dominantly quartzo-feldspathic and typically contain blue-grey augen quartz reaching up to 10 cm at their largest dimension, with smaller feldspar augen. There are also granitoid gneisses.

2.2.2 The semipelitic schist and paragneiss belt: From the Langoa Cave to the outcrops of mylonitic gneiss and calc-alkaline intrusion, the Mulatos River outcrops comprise semipelitic rocks. Initially, there are schists followed by schistose gneisses. The rocks demonstrate their sedimentary origin (paragneiss) through their high content of muscovite, biotite, and garnet, and their intercalations of quartz schist and graphitic schist. There are garnetiferous gneiss boulders with a high garnet content (up to 1 cm in size) that may be derived from this sector. In panning the rivers in this zone, the heavy minerals show a high garnet content.

2.2.3 The mylonitic gneiss and orthogneiss belt: In this zone of the Mulatos River, the outcrops comprise mylonitic gneiss and plutonic intrusive rocks with or without deformation (orthogneiss).

The mylonitic gneisses exhibit a strong tectonic fabric in many locations, and the boulders contain feldspar augen (up to 1 cm in size) that demonstrate syntectonic growth with “Z” or “S” shaped rotation. These are porphyroclasts (porphyritic crystals rotated and grown by mylonitization) within the mylonites. In composition, most appear to be paragneisses due to their biotite and muscovite content, and in one boulder, a band of banded chert 5 cm thick was observed. However, there are also mylonitic gneiss boulders of quartz-plagioclase (epidotized)-biotite composition, which are orthogneisses derived from calc-alkaline intrusives (see below).

The orthogneisses of the calc-alkaline suite in this belt appear in outcrops and large boulders entering the Mulatos River at the level of the Zapalá River, further upstream from the outcrop belt on the map. In this site and in boulders, there is a mix of compositions including: gabbro, dolerite, diorite, monzonite, tonalite, and granite. The most common is diorite-tonalite with mafic xenoliths and epidotized plagioclase veins ($\pm$ garnet) up to 10 cm thick that cross-cut the xenoliths and the tectonic fabric. Some boulders of this composition are biotite-hornblende orthogneiss with tectonic fabric, while others show no deformation or metamorphism (but do contain epidote veins). The gneissic boulders are marked by calcite-quartz-biotite-sulphide veins that follow the tectonic foliation.

For other compositional types, dolerite boulders (undeformed) are scarce; there are boulders of metagabbros and a rounded porphyritic hornblende gabbro. There are large boulders of leucocratic monzonite with and without deformation, and boulders of undeformed granites of aplogranite type (medium-grained), coarse-grained granite, and granite with pink K-feldspar porphyries.

2.3 The Metamorphic Complex in exotic boulders

This comprises lithologies of boulders that are not found *in situ* in the Mulatos and Anatenorio rivers. These can be divided into the “exotic suite” (see map) and other exotic boulders.

2.3.1 Boulders of the exotic suite

2.3.1a Pale calc-silicate rocks: These form a large part of the exotic suite. They are normally mottled pink-green in colour. The pink represents the original dolomitic rock?, and the green represents the epidotization stage and the formation of calc-silicate metamorphic minerals. This rock is intercalated with cherts (white-grey); dark green laminated calcareous metatuffs?, with elongated fragments of quartz and feldspar; dark para-amphibolite bands up to 5 cm thick and ferruginous bands. There are also pale limestone boulders. In some boulders, black amphibole metamorphic crystals grow up to 1 cm long in a carbonate matrix.

In the boulders, primary autobrecciation is noted, likely related to the stage of epidotization and the introduction of magnetite. Subsequently, there are calcite veins, up to 10 cm thick, forming agmatic structures. Some boulders or sections of boulders are gneissic with calcite veins parallel to the gneissic foliation. Dark asbestiform amphibole, quartz, sulphides, and magnetite are found within the calcite veins.

2.3.1.b Dark calc-silicate rocks?: These comprise fine to coarse-grained rocks, heavy, with dark amphibole and an abundance of garnet (up to 30%), and in many cases with epidote, sulphides, and magnetite. Some have an eclogite appearance.

Many of the samples contain magnetite, which may contribute to the rocks' high weight. Many have disseminated sulphides that give the boulders a striking lead-grey metallic lustre.



2.3.1.c Metalavas: There are boulders of dark grey-green, fine-grained rocks that have a basaltic composition with euhedral plagioclase crystals, altered in certain boulders to epidote. In some cases, there are bands of brecciated epidotic material (likely from an original feldspathic vein). In the most epidotized examples, there are many sulphides that give the boulders a lead-grey metallic lustre. There was one boulder of this lithology with structures resembling pillow lavas.

2.3.2 The derivation of the exotic suite

Down the Mulatos River, there are scarce boulders of the exotic suite (metalavas and garnetiferous amphibolite) before the Zapalá River, but the complete suite (including the calc-silicate part) is developed at the level of an unnamed river that enters on the western side between the Zapalá and Tigre rivers. Further south, the Tigre, Niágara Chico, and Niágara rivers carry boulders from the suite. Although we do not have information on the confluences on the other side of the Mulatos River, it seems certain that the exotic suite outcrops to the west of the Mulatos River in this sector, although we did not see it in the Anatenorio River section that crosses the same Andean trend to the west.

2.3.3 Other exotic boulders

These include cleaved siliceous rocks of the metachert or acidic metalava type; ferruginous schists; greenschists with fuchsite; black metalutites; and black biotitic schists.

2.4 The Non-Metamorphic Complex in situ

2.4.1 Lavas and volcaniclastics

The change from the Metamorphic Complex to the Non-Metamorphic Complex is marked in the Mulatos River by the appearance of pale grey, glassy, acidic lavas of rhyolite type with phenocrysts of feldspar and biotite, and with weak cleavage. There are intercalations of black slates. Further east of the contact, the lavas are darker and less deformed, and they retain feldspathic phenocrysts up to 4 mm long.

Along the Negro River and further downstream, there is a sequence of deformed lavas and volcaniclastics. The lavas include fine white types, with quartz phenocrysts, and glassy siliceous types that are pink and red amygdaloidal. In one boulder, a contact is noted between a grey glassy lava and a pink porphyritic lava with fragments and protrusions of the grey lava and clasts of other lava types. In this case, it is clear that the breccia is a lava flow breccia and not a pyroclastic breccia. The volcaniclastics form massive outcrops without bedding structures. They consist of pyroclastic breccias with angular clasts of acidic volcanic material, up to 20 cm long, and banded chert. In an outcrop at the confluence of the Negro River, these rocks are in lateral contact with grey glassy lavas.

There are boulders in the Mulatos River of greenish volcanosedimentary rocks with cross-stratification, which may be related to the lava/volcaniclastic sequence.

Further east from the sequence of pale lavas with volcanoclastics, fine black lavas altered with feldspar porphyries outcrop. These are followed by outcrops of black acidic lavas, non-porphyrific, with an outcrop of banded chert?, which could also be a lava.

2.4.2 Carbonate rocks

Between the volcanic outcrop zones, there are “in situ” carbonate rocks. In the far west, dark limestones outcrop with or without fossils and with a tectonic cleavage. Next come purple limestones and calcilutites that are heavily deformed; followed by a sequence of calcilutites, black clays, and pellet limestones that are lightly deformed. Sedimentary truncations demonstrate that this last sequence is younger at the top.

Also, in this sector and further down, there are large blocks with intercalations of black and creamy/yellow limestones (dolomites?) intercalated, in one block, with pale quartzite and in another, with black chert. There are also blocks that appear to be dolomite breccias further down in the Río Mulatos.

2.4.3 Granite (of Abitagua)

The first granite outcrop down the Mulatos River is near the confluence with the Katachi River. It is a medium-grained grey granite with biotite and hornblende. This can be interpreted as a marginal intrusion of the main body. However, further up, near the confluence with the Yarapa River, there are blocks of quartz porphyry (with round quartz megacrysts up to 1 cm long) near outcrops of lavas with zones of pink feldspar megacrysts up to 6 mm long (feldspathization?).

The main granite body was found at the end of the traverse. The first outcrops show a medium-grained grey granite with biotite and hornblende, with mafic xenoliths including self-brecciated mafic dikes. The last outcrops show a transition to a coarse-grained biotitic granite with pink K-feldspar that intrudes into the previous granite. There are mafic and porphyry dikes.

2.5 The Non-Metamorphic Complex in exotic blocks

Between the outcrops of carbonate rocks and those of lavas and volcanoclastics, there is an absence of outcrops in the Mulatos River where the following exotic blocks occur (which are not noted in situ):

- (a) Fine sandstones of yellow, purple, and red colour
- (b) Green and pale cherts
- (c) Carbonaceous clays
- (d) Amphibole porphyry

A little further down from the confluence of the Negro River, there are also blocks of conglomerate with a fine sandstone matrix.



3. STRUCTURE AND METAMORPHISM

3.1 The Metamorphic Complex

In the Anatenorio River section, up to three phases of deformation are noted. The first two are penetrative and have an Andean strike; the second involves folding of the gneissic foliation (S1). Associated with the second deformation (S2), there is a lineation with a strong southward plunge, particularly marked by the elongation of quartz and feldspar eyes (rodding). D2 also folds the quartz veins formed during D1.

At the confluence of the Anatenorio and Langoa rivers, a third deformation is found locally with an E-strike of monoclinical folds plunging gently to the W, without penetrative cleavage. This deformation is responsible for the gentle dips of S2 in the Cueva de Langoa area. In this zone, there are also very gentle folds with a N-strike (D4?).

Further down the Mulatos River, D3 disappears through the semipelitic paragneiss belt.

In this sector of gneiss and schists (Anatenorio-Mulatos), the metamorphic grade barely reaches amphibolite metamorphic facies (presence of amphibolite and augen feldspar). The lack of migmatitic veins indicates that the rocks have not reached the stage of partial melting of high amphibolite facies.

In the area of the mylonitic gneisses and orthogneiss, there appears to be another tectonic environment. The deformation (gneissification) of the calc-alkaline plutons is selective, with deformed and non-deformed zones. Taking into account the presence of the mylonitic gneisses, this zone can be interpreted as a single phase of deformation through restricted drag zones (mylonitization/gneissification) with probably horizontal movement. The epidotized feldspathic veins, which are noted in the orthogneiss and the non-deformed intrusives, are related to late minor drag zones. These cut the gneissic foliation with sinistral or dextral movements. The blocks of the exotic complex also demonstrate the same tectonic environment, with metamorphic minerals of amphibole and garnet in affected zones, and with non-deformed zones.

3.2 The Non-Metamorphic Complex

The tectonic discontinuity that divides the Metamorphic Complex from the Non-Metamorphic Complex must be a fundamental structure. It represents a lithological change as well as a change in structural and metamorphic environment. However, the same structure, or its remobilization, has affected the Non-Metamorphic Complex, producing a tectonic cleavage in the rocks as far as the Negro River. This cleavage is axial planar to folds with a southward plunge, and the calcilutites show minor "M" structures that form at the axial zone of major folds. For the rest of the Non-Metamorphic Complex, it can be noted that the dip of the bedding? is not horizontal and may be related to gentle regional folds.

4. CORRELATION AND INTERPRETATION

The belt of the Metamorphic Complex has similarities to the Baños-Puyo section to the south: the gneisses and schists, essentially semipelitic, followed to the east by the belt of calc-alkaline intrusives, partially deformed. The calc-alkaline lithological assemblage is identical to the intrusives of the Río Verde-Azafrán sector and also to those of the Río Abanico (see Baños-Puyo and Guamote-Macas reports of the Cordillera Real Project, 1986). This lithological correlation includes the identification of gabbro with round hornblendes in the three sectors.

There are some sectors of the Río Anatenorio section that appear like the rocks of the Papallacta-Baeza section, especially the greenschists.

Regarding the origin of the exotic assemblage, in a provisional interpretation without thin sections, I would propose a sequence of basaltic lavas and carbonates. The carbonates would include dolomites, cherts, limestones, calcareous tuffs, and ferruginous calcilutites. The ferruginous calcilutites could be the protoliths of the magnetite-bearing garnet amphibolites. There is also evidence of intercalations of carbonate and iron rocks.

The Non-Metamorphic Complex comprises the Abitagua Granite, the volcanoclastic lavas, and the carbonate rocks. Field evidence indicates, but does not prove, that the granite intrudes into rocks which may belong to the Misahuallí Member (Lower Cretaceous) of the Chapiza Formation. The carbonate rocks could be lithologically correlated with the Macuma Formation (Carboniferous), the Santiago Formation (Jurassic), or the Napo Formation (Cretaceous). Due to the presence of pellet phosphatic limestones? (see 5.2.4), the correlation with the Napo is preferred. In any lithological-structural interpretation of this sector, it is important to take into account the presence of new blocks of fine sandstones in the area without outcrops between the carbonate rocks (Napo?) and lavas (Misahuallí?). These sediments may be part of the Chapiza Formation, which contains dolomites (Baldock, 1982), or the Lower Napo.

5. ECONOMIC GEOLOGY

5.1 Metallic minerals

5.1.1 Gold: It was not observed during panning, primarily due to the difficulties in distinguishing it and the abundance of sulphides. We will await the geochemical analysis of the heavy samples to determine the auriferous potential of the sector.



5.1.2 Copper/sulphides: the following indications have been observed:

- (1) In an outcrop of semipelitic gneiss near the confluence of the Tigre River, there are small mineralizations of chalcopyrite/bornite/malachite/pyrite, associated with a 2 cm thick quartz band (vein?).
- (2) In blocks of pale calc-silicate rock from the exotic assemblage, there are calcite veins with chalcopyrite/pyrite mineralization in zones up to 3×3 cm in size.
- (3) In blocks of epidotized metalava from the exotic assemblage, those having a lead-grey metallic lustre, there is disseminated chalcopyrite/pyrite mineralisation.
- (4) In blocks of black garnetiferous calc-silicate amphibolite? from the exotic assemblage, which also have a lead-grey metallic lustre, there is disseminated chalcopyrite/pyrite mineralization.
- (5) In the Niágara Chico River, there are blocks of black biotitic schist with disseminated chalcopyrite/pyrite. It is possible that this schist comes from the biotite-bearing calcite veins found in the orthogneisses of the deformed calc-alkaline plutons.
- (6) There is plenty of chalcopyrite/pyrite in washed fluvial samples from the Tigre, Niágara Chico, and Mulatos rivers (around the area of these confluences). There is no doubt that these sulphides are associated with the mineralized exotic blocks.

5.1.3 Chromium: We saw a block of schist with fuchsite (chrome muscovite).

5.1.4 Hematite?: Below the Zapalá River, in the Mulatos River, in an outcrop of semipelitic gneiss, there is a quartz vein with a platy mineral that looks like hematite due to its colour and hardness, but its streak is black/grey and not brown (like hematite). A sample will be sent for X-ray study.

5.1.5 Magnetite: This mineral occurs in the pale calc-silicate and black calc-silicate? exotic blocks. In the former, it occurs with calcite veins associated with sulphides and asbestos. There was also a pale-green calc-silicate block with magnetite veins 1-2 cm thick, forming about 3% of the block.

In the black calc-silicate blocks? with amphibole and garnet, the magnetite content probably accounts for the high weight of the rock. In these rocks, magnetite can be distinguished with a hand lens as crystals, with triangular faces, up to 1 mm in size.

It is possible that the magnetite comes from ferruginous layers of the carbonate sequence. There are blocks with defined ferruginous layers, and in one example, the layer contains magnetite and is intercalated with carbonate containing metamorphic black amphibole.

5.2 Industrial rocks and non-metallic minerals

5.2.1 Asbestos: Black amphibole of asbestiform structure forms in masses in the garnetiferous amphibolites in black calc-silicate exotic blocks? and also in calcite veins in pale calc-silicate blocks. The mineral is probably actinolite, which has no commercial significance. Pale green asbestiform crystals form along fracture zones in massive dolomitic blocks? (without gneissic structure).

5.2.2 Biotite (mica): There are zones of biotite (biotite rock) in calcite veins within the orthogneisses, but they have no commercial significance.

5.2.3 Carbonate: There are dolomites, limestones, and calcite veins (up to 10 cm thick) in the exotic blocks. There are also black limestones and calcilutites (Napo Fm.?) in the Non-Metamorphic assemblage.

5.2.4 Phosphate: the pellet limestone of the non-metamorphic assemblage may be phosphatic. The pellets are brown-red in colour (some strongly reddish) up to 3 mm long in a carbonate matrix. There are descriptions and photographs of a similar rock (phosphatic limestone) in Wilkinson (1982) that comes from the Upper Napo and contains 30% P_2O_5 . A sample will be sent for analysis.

The layer is about 50 cm thick and is intercalated with red calcilutite and black shales. There is a weak cleavage and the sequence dips at 40° to the south, exiting through the nose of a regional fold.

6. RECOMMENDATIONS

6.1 Administrative

The traverse along the Mulatos River does not adjust to the normal commissions of INEMIN. Although we came out alive and “without incident”, the following must be taken into account for future sections like the Mulatos:

- (1) Due to the danger of the area and the necessary forces, the labourers rightly ask for high daily wages (more than planned).
- (2) Provisions ran out on the twelfth day; therefore, it is necessary to better calculate the quantities of provisions to be carried and the number of labourers.
- (3) It is madness to walk through such a dangerous sector without radio communication. This Project is not going to carry out more sections of this kind until we have radios.



6.2 More detailed studies

Apart from the possibility of phosphates, there is only one area to return to the Mulatos River for economic reasons. This is in search of the outcrops of the exotic assemblage that carries disseminated copper and magnetite mineralization, studying these rocks and sampling the area geochemically in detail. Although these rocks have not been seen “in situ”, their lithologies (basaltic lavas and carbonate without clastic material), their metamorphism (skarn type), and their deformation (local drag zones) indicate an environment of mineral potential. This was confirmed by the mineralization seen in the blocks. After studying the thin sections and the geochemical results of the fluvial and heavy samples, this Project will program a commission to return to the Mulatos River in 1987?. In this commission, it is also possible to verify, further up from the confluence of the Anatenorio River, the existence of the “ophiolites” reported by Sauer (1965); those that have 1.5% Ni. It is possible that his “ophiolites” are the black garnetiferous amphibolites that also carry “hornblende asbestos” as he reported.

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Ing. Ramiro Bermúdez

Dr. Martin Litherland

CORDILLERA REAL PROJECT

ATTACH. Structural-geological map (1)
Map of petrographic and geochemical sample locations (1)

No. 3394

QUITO, JULY 31, 1986

TO : GERENTE TÉCNICO

FROM : ING. RAMIRO BERMÚDEZ and DR. MARTIN LITHERLAND

SUBJECT : Technical Report of the commission carried out to Baños-Puyo and Guamote-Huamboya from June 25 to July 11, 1986

SUMMARY:

The Geological Research Project of the Cordillera Real, executed in conjunction with the British Mission, carried out this commission to continue the study of the programmed sections 5 and 6: Baños-Puyo and Guamote-Huamboya.

A study of the metamorphic and igneous rocks of the Cordillera was executed, focusing on their structural-geological aspects as well as mineral indications. Additionally, heavy and fluvial sediment sampling was conducted, along with the collection of samples for laboratory study (thin sections) and age dating. Due to inclement weather and difficult terrain (heavy rains, flooded rivers, landslides, etc.), the Alao-Cushnapaccha-Laguna Negra-La Magdalena-El Placer-Huamboya (Elvira) traverse was only partially completed.

1. INTRODUCTION

1.1 Objective

To continue the study of the metamorphic, semi-metamorphic, and igneous rocks of the Cordillera Real.

1.2. Assigned personnel

Project Brigade No. 1, comprised of:

- Dr. Martin Litherland (ODA)
- Ing. Ramiro Bermúdez (INEMIN)
- Sr. Alfonso Vaca (INEMIN, vehicle driving and maintenance)

A mission Jeep Land Rover AT-0068 was used for transport.



1.3 Geographical aspects

1.3.1 Location: The area of section 5 (Baños-Puyo) is located southeast of the capital, between the provinces of Tungurahua and Napo, approximately 153 km away; section 6 (Guamote-Huamboya) is southeast of Quito, approximately 200 km away, between the provinces of Chimborazo and Morona Santiago.

Section 5:	Longitude	:	78° 30'	y	78° 06'	W
	Latitude	:	01° 20'	y	01° 30'	S
Section 6:	Longitude	:	78° 40'	y	78° 22'	W
	Latitude	:	01° 45'	y	02° 55'	S

1.3.2 Climate and vegetation: Both climate and vegetation are directly related to the elevations of the sectors.

In Baños-Puyo, elevations fluctuate between $\pm$ 1850 mamsl and 1200 mamsl with a temperate climate that averages 18°C; in Licto-Huamboya, we have elevations between $\pm$ 2700 mamsl and 4000 mamsl with a climate ranging from Andean temperate to Andean cold, with temperatures varying between approximately 8°C and 12°C.

The vegetation in both sectors corresponds to the climate; in the temperate zone, there is exuberant non-tropical jungle-type vegetation. In the temperate to cold Andean climate, the vegetation is typical of the páramo: grasslands (*pajonales*) and scrubland (*chaparro*), with high-altitude areas experiencing strong winds and almost constant rainfall.

1.3.3 Hydrography: In the Baños-Puyo section, the Pastaza River constitutes the main hydrographic axis, which also receives the waters of the Chambo and Patate rivers. Along its west-to-east course, its left-bank tributaries include: Río Blanco, Río Verde, and Río Topo, among others; on the other bank: Río Chinchin, Río Negro, and Río Encanto.

Licto-Huamboya: The Alao River constitutes the main hydrographic axis, which also receives the waters of the Chambo River. Its headwaters originate in the Laguna Negra sector at $\pm$ 4000 mamsl, with a southwest to west-southwest course. Among its main confluents is the Maguazo River on the left bank. Toward the east, in the sector known as Placer, the Palora River - flowing west to east - becomes the primary hydrographic network.

1.3.4 Population: In Baños-Puyo, the population of this sector is dedicated to agricultural and livestock activities, with Baños being a privileged location for national and international tourism due to its location.

Licto-Huamboya: Most of the population between Licto and Alao is dedicated to agricultural and livestock labour.

1.3.5 Roadways: This area has a first-order highway: Quito-Baños-Puyo, which constitutes one of the main entrances to the Ecuadorian Oriente (Amazon region), with an approximate distance of 218 km. Additionally, in the towns of Shell and Mera, there are heliports for air transportation between the Oriente and the Sierra.

Licto-Huamboya: The South Pan-American Highway (Quito-Riobamba), at a distance of approximately 175 km, serves as the link to the area. The Licto-Pungalá-Alao-Cubillín segment is traversed via a third-order road, which is mostly affected by landslides and waterfalls; unsafe bridges make access difficult. Finally, the Cubillín-Laguna Negra-El Placer sector is accessed via a pack trail (bridle path). Approximately 40% of the roadway marked on the area's census maps is not transitable due to a lack of proper maintenance and, in part, because the few inhabitants who once lived in the Huamboya (Elvira) zone have left.

1.3.6 Land use: In both areas, a high percentage of the land is dedicated to agricultural and livestock activities.

In sectors where volcanic, metamorphic, or intrusive rocks outcrop, they are used for the maintenance and stabilization of the roads.

1.3.7 Industries: The agricultural and livestock industries constitute an important source for the development of these areas.

Tourism toward Baños-Puyo is favoured by a series of tourist sites, including: thermal pools (Salado, Nuevas, de la Virgen, etc.), Agoyán waterfall, Inés María waterfalls, and visits for mountaineering enthusiasts to the Tungurahua crater (5300 mamsl).

1.4 Previous works

The geology of the Baños-Puyo road has been studied by Sauer (1965), Kennerley (1971), Trouw (1976), and Herbert (1977). In the Licto-Huamboya area, Sauer (1965), in his book *Geología del Ecuador*, provides a partial description of the sector, which appears to be the only known study in this area.

1.5 Work methodology

The following cartographic bases were utilized:

- Baños-Puyo: Census sheets for Baños and Mera, 1:50000 scale from the IGM, 1973
- Licto-Huamboya: The Guamote topographic sheet, 1:50000 scale, and the Río Sangay and Huamboya planimetric sheets from the IGM, 1973
- Aerial photographs covering both sections at scales of 1:40000 and 1:60000



The following methodology was employed:

- “In-situ” geological observations
- Structural study
- Sample collection for petrological study (45) and for dating (3)
- Heavy sediment (18) and fluvial (19) sampling

1.6 Geomorphology

Correlating the elevations of the two sections, which fluctuate between ± 1200 mamsl (Puyo) and 4000 mamsl (Laguna Negra), we find two distinct zones: one with moderate slopes constituting the foothills of the Cordillera Real, and another with steep slopes and deep ravines (*quebradas*) that make ascent and descent difficult.

2. LITHOLOGY

2.1 Introduction

The geology of the Patate-Baños-Puyo and Licto-La Plancha (Huamboya) sections has much in common; therefore, these units are described together. The Metamorphic Complex is divided into informal groups of lithological association. In the east, there is the Patate group (Patate-Puyo) and the Alao group (Licto-Huamboya). To the east of a line (Baños front) passing near Baños and near Laguna Negra (Licto-Huamboya), a different group begins - the Pastaza group (Patate-Puyo) and the Palora group (Licto-Huamboya). Further east in the Patate-Puyo section, there are plutonic rocks and metamorphic rocks of Cretaceous age?

2.2 Metamorphic Complex

2.2.1 The Patate suite: Consists of black and green rocks of low-grade metamorphism with two strong cleavages (S1 and S2). The black rocks are graphitic phyllites, locally laminated with metasilts (rarely showing graded bedding). There are also zones of silvery sericitic slate and green chloritic phyllites. A band of black marble no more than 50 cm thick was found, containing black calcite. In the Patate River, where the black rocks are intercalated with the green ones, there are bands of fine-grained black quartzite and cherts.

The green rocks are mostly massive with less developed cleavages. Their colour varies from medium green to medium grey-green, with a mafic (basic) composition of basaltic origin. There is an outcrop with a band of ultramafic schist.

From the Patate River to Baños, there are two belts of green rocks and one belt of metasedimentary rocks. In the Patate River, both lithologies appear mixed. By mapping minor folds (see structural profile), it can be provisionally determined that the green rocks are structurally below the black rocks (not necessarily stratigraphically).

2.2.2 The Patate suite: It outcrops from where the Metamorphic Complex begins below the Cenozoic lavas south of Pungalá, reaching the drainage divide of the Cordillera Real near Laguna Negra. West of Alao, the structure is simple with horizontal open D1 folds and a single S1 cleavage, providing a sequence that can be considered horizontal. To the east of Alao, there is a strong second cleavage. In Pungalá, the first outcrops are graphitic black slates with quartzites and cherts; then, it transitions through greenstones and the Peltetec Ophiolite (see 2.2.3). These are followed by massive, fine-grained black quartzites with black phyllites; blocks of pale quartzites; from Alao to Laguna Negra, there are metabasaltic-type greenstones with quartz and calcite veins.

2.2.3 The Peltetec ophiolite: This body outcrops for about 4 km along the road to the Maguazo River. It consists of black serpentinites, metalavas with pillow structures, and minor coarse-grained metagabbros. The rocks are massive with little cleavage development. The pillows are of two types: pale spilites on the inside with black obsidian-like rims; and dark centres with pale rims. There are movement zones marked by breccias and slickensides. There are also pre-tectonic breccias (cut by S1) of a conglomeratic type and serpentinite clasts within basalt. There are in-situ veins and wider vein blocks containing quartz, epidote, and blue asbestos.

Regionally, it is probable that the Peltetec Ophiolite forms part of the greenstone series. The relationships with the metasedimentary rocks are not clear along the road, although there is some evidence of interstratification. A great thickness of the ophiolitic body can be seen, accounting for the subhorizontal stratum and the outcrops located (visually) further up in the Alao Valley.

2.2.4 The Pastaza suite: Between Baños and the Azafrán “Granite”, there is a series of the Metamorphic Complex of higher grade (reaching the amphibolite facies) and of a metasedimentary-metaplutonic type, cut by penetrative S1 and S2, and in certain places, penetrative S3 (see structural profile). There is an abrupt change at the Blanco River where low-grade black slates with an unusual structural style intervene. Blue quartz continues in the rocks up to the Blanco River.

The complex begins near Baños on the north side of the Pastaza River across from the entrance of the Ulba River. Here, granitoid orthogneiss and quartzites with blue quartz and amethyst are found in the rock and in the veins that cut them. Further east, there are biotitic garnet-bearing paragneiss, garnet-bearing graphitic schists, garnet-bearing muscovite schists with chloritoid ($\pm$ kyanite), granitoid orthogneiss with deformed mafic xenoliths, chlorite schists, quartz schists, and muscovite-biotite schists. There are also minor lithologies such as amphibolite and quartzite.

The Pastaza suite consists of a pelitic to semipelitic sequence with gneissified igneous rocks of granitoid composition and pre-tectonic doleritic dikes.



2.2.5 The Palora suite: At the summit of Laguna Negra, there is a marked lithological change from greenstones to a granitoid orthogneiss (Baños Front) that forms the western part of the Palora Complex.

From Laguna Verde to El Placer (± 4 km), the predominant rock is a coarse-grained granite or a granitoid gneiss, both featuring blue quartz; with minor quartzites and quartzitic schists containing blue quartz. An amphibolite band was observed in situ.

To the east of El Placer, there are loose blocks derived from the mountains to the south, which show a transition from blue-quartz granitoid orthogneiss to muscovite and quartziferous schists with garnet and chloritoid; quartzites and a fuchsite quartzite (the final sample).

2.2.6 Rocks of ?Cretaceous age: Rocks assigned to the Margajitas Group and the Tena Formation are found between the Azafrán and Abitagua plutons on the Baños-Puyo road. These are muscovite and graphite schists and quartz and chlorite phyllites. A single cleavage cuts the sequence. Original blue quartz clasts are noted in the quartzose phyllites.

There are boulders in the Topo River probably derived from this sequence. There is a marble containing lamellibranches (Tena Fm.?), and a deformed conglomeratic breccia with clasts of the Azafrán “monzonite” included in a black slate.

2.3 Igneous rocks and veins

2.3.1 The Azafrán “Granite”: This medium- to coarse-grained body is well known due to access via the Baños-Puyo road. However, it is not a granite due to its low quartz content (estimated at 5-10% in the field). It also contains epidote and chlorite/biotite. The colour index suggests a quartz syenite, but here it is called “monzonite” until the feldspars are identified.

The core of the body shows a weak tectonic orientation of minerals, but along the margins, the rock is a feldspathic gneiss (gneissic monzonite) (see “XM” on the map). The pluton section has bands of schist intruded by monzonite dikes, and along the margins, there are pegmatitic veins with tourmaline ± 15 cm thick.

In the core of the Azafrán pluton, there is a quarry with an extensive outcrop showing great detail. The weak tectonic foliation is parallel to mylonitic zones that carry bands (10 cm) of green phyllites which may be mylonitized monzonite. The pluton partially intrudes the mylonitic foliation, and subsequently, a low-angle crenulation cleavage developed, related to mylonitic zones in the pluton with sinistral displacement of up to 3 cm. Irregularly shaped quartz veins up to 40 cm thick carry smoky quartz in the contact zones (2 cm).

2.3.2 The Abitagua granite: This pluton is also very well-known and forms an elongated body (100 km) from Baños-Puyo to Baeza. In the outcrops along the Baños-

Puyo road, the pluton can be divided into two parts: the western part, which is coarse-grained with K-feldspar megacrysts up to 2 cm long and features fresher outcrops; and the eastern part, consisting of equigranular granite with heavy weathering, where the material is excavated and converted into a gravel quarry.

In these quarries, quartz porphyry dikes up to 5 cm thick are observed, containing round and euhedral crystals and running parallel to the most prominent joint set. There are also kaolinized monzonite dikes. The porphyry dikes carry rounded xenoliths of basalt, andesite, and feldspar porphyry; some are laterized, while others are fresh and fall away as boulders. Original banding with a strike off the axis of the pluton is also noted.

2.3.3 Blue quartz granites and orthogneiss: These were mentioned in section 2.2 (Metamorphic Complex); only in the Palora complex are there undeformed granites.

2.3.4 Diorites: These occur in both sections. Along the Baños-Puyo road, there is a medium-grained outcrop with weak metamorphism on the western side of the Azafrán “monzonite”. In the Río Verde, large boulders of this material predominate, some with hornblende phenocrysts up to 1 cm long, others with crossing or parallel epidotization veins. These blocks demonstrate the existence of a large diorite body further north. There are also diorite blocks in the Río Topo and at the confluence of the Pastaza to the south.

There are loose metadiorite blocks slightly east of El Placer along the Licto-Huamboya crossing.

2.3.5 Other veins: Quartz veins are common in the Metamorphic Complex, parallel to the penetrative S1 and S2 schistosity. Calcite veins form in the greenstones and graphitic phyllites.

There is an apparent concentration of quartz veins up to 1 m thick along S2 near the Baños front in the Laguna Verde area (Licto-Huamboya). The veins are mineralized (see 5.1).

3. STRUCTURE AND METAMORPHISM



There appears to be a structural symmetry of penetrative cleavage throughout the Cordillera Real. At the western extreme, by Peltetec, there is only a single cleavage. Further east in the Alao and Patate suites, S₂ (second cleavage) is developed, and it continues through the Pastaza and Palora complexes until the Cretaceous rocks, where once again only a single cleavage appears.

D₁ folds at Peltetec are open, but in the Patate suite (see structural profile), there is evidence that S₁ is parallel to S₀ (bedding), and the structural complex can be interpreted as D₂ refolding D₁ thrust structures (nappes). This may indicate a change in the tectonic regime from D₁ at Peltetec to Patate.

Minor D₂ folds are common, and their shape (vergence) can be used to locate major folds (see structural profile). The folds are closed to tight.

D₃ is invoked to explain all structures post-dating D₂. Thus, along Patate-Puyo, there is a D₃ antiform at the western extreme; a subvertical S₃ refoliation zone near the Ulba River; and a strong, low-angle S₃ zone along the Blanco River. This could be a tectonic segment brought from above from structural levels equivalent to the Papallacta-Baeza sector (Litherland et al., 1986).

The tectonic dislocations shown on the map are inferred. The fundamental feature may be the Baños tectonic front (D₂), which separates distinct lithologies and metamorphic grades. Thus, to the west, there is greenschist facies, and to the east, there is amphibolite facies (hornblende, garnet, kyanite). These minerals are related to the S₂ cleavage, and there is no doubt that the metamorphic grade increases in zones with S₂ refoliation.

4. CORRELATION

The Patate and Alao suites, as well as those of Pastaza and Palora, can undoubtedly be correlated. Both correlations are supported by their geographic distributions, by the strike of the Cordillera, and by the rocks themselves. The blue-quartz orthogneiss/granite east of the Baños front can be correlated with the Palora Complex; to the north, it reaches the Pastaza and Papallacta Complex (Litherland et al., 1986).

Thus, the Metamorphic Complex is being segmented both tectonically and lithologically, from the volcanic rocks to the west, the metamorphic core with blue quartz granites in the centre, to the Cretaceous rocks to the east.

The schistosity in each segment (S₁, S₂, S₃) can be correlated, but they may also have no temporal relationship. The observations refer to the structural history of each outcrop, nothing more. For example, S₁ cuts clastic blue quartz in the Cretaceous? rocks. Could it

be that this quartz comes from the erosion of the blue quartz granites to the west, where it formed along S2? In this case, the structures could not be correlated.

5. ECONOMIC GEOLOGY

5.1 Metallic minerals

5.1.1 Gold: Along the Patate-Baños-Puyo section, gold specks were found by panning in the Pastaza River and all its tributaries east of the Blanco River. The highest concentrations occurred in the Verde River. This gold distribution along Patate-Baños-Puyo corresponds to the Map of Alluvial Gold Potential (DGGM, 1983). Along Licto-Huamboya, there were only a few gold specks in the Alao River and none in the panned tributaries. There were also a few gold specks in the panned sample from the Palora River.

From the few studies conducted, it seems that the gold may be related to the regional geology, specifically hosted by quartz veins. The volcanosedimentary suites of Patate and Alao are gold-poor, while to the east of the Baños front in the Pastaza complex, there are more specks in the panned samples. The presence of many diorite blocks has been observed in the Verde River, giving the impression of the existence of a large diorite body (not identified on the 1:100000 scale geological map) further north, from which gold disseminated or concentrated by the intrusive may originate.

5.1.2 Silver: There are occurrences of silver in the Index Map of Metallic Minerals (INEMIN, 1985) and that of Goossens (1969) in the summit area of Laguna Negra and along the Baños front, where we saw a wide zone of mineralized quartz veins. Thus, it is clear that the silver comes from this same zone, with possible tectonic control. The indigenous people of the Alao area also speak of the occurrence of silver in that region, having found an adit 3 km east of Alao.

5.1.3 Copper: About 500 m west of the Blanco River on the Baños-Puyo road, there is a garnet-bearing muscovite schist with kyanite? that contains disseminations of pyrite, chalcopyrite, and bornite. In the same section on the Goossens (1969) map, there is a copper index by the Verde River, where we find gold and diorite blocks with magnetite mineralization.

Along Licto-Huamboya in the summit zone, there is chalcopyrite mineralization in quartz veins associated with hematite (sphalerite?) in aggregates sized up to 2×1×1 cm. Also, in the hot springs of El Placer, there is a block of greenstone that has come from above the summit, which contains disseminated chalcopyrite in an original 3 mm thick band within the metalava.

On the road to Peltetec, above the road to Alao, approximately 50 m above the contact with the Peltetec Ophiolite, there are quartzites and black slates in a zone about 20 cm wide with mineralization (malachite/azurite) along veins and associated with kaolin? Above this, there is a local development in the structural profile of a lateritic-type gossan



with malachite. It is very likely that the copper came from the ophiolite through hydrothermal precipitation.

5.1.4 Chromium: The mineral fuchsite (chrome muscovite) of an intense green colour was noted in the last sample taken from the Licto-Huamboya section. The importance of this occurrence will not be known until a microscopic examination is performed.

5.1.5 Iron and pyrite: There is minor magnetite mineralization associated with epidote along fracture surfaces in a diorite block in the Verde River (Baños-Puyo). There is also an elliptical pyrite concretion with axes of 7×7×3 cm in a black shale belonging to a boulder in the Topo River. In the vein zone at the Licto-Huamboya summit, pyrite is well-developed, and the same mineral is present in both sections disseminated in graphitic rocks and green metalavas.

5.1.6 Lead: We found two occurrences of galena mineralization in the vein zone at the Licto-Huamboya summit. The crystal aggregates we saw do not exceed 1×1×1 cm, but the indigenous people showed us mineralized rocks with larger developments.

5.2 Industrial rocks and non-metallic minerals

5.2.1 Asbestos: Epidote, quartz, blue asbestos, and talc? veins occur in the Peltetec Ophiolite. There are blocks with vein concentrations up to 3 cm wide with asbestos fibres up to 2 cm long.

5.2.2 Kaolin: In the Abitagua granite, we saw a “monzonitic” dike (from Azafrán?) 3 m thick that is mostly altered to kaolin. The main impurity is quartz (approx. 5-10%) in 1 mm grains. There are few altered mafic minerals.

5.2.3 Quartz: Quartz with weak smoky-blue and amethystine colours occurs in the Pastaza and Palora complexes, but it is of no interest to the jewellery industry. Some small transparent quartz crystals were found in the Chinchín Grande River (Baños-Puyo).

5.2.4 Feldspar: The Azafrán “monzonite” is composed of approximately 85-90% feldspar, and there is a concentration of large feldspar crystals in 10 cm wide layers in the marginal pegmatites.

5.2.5 Graphite: The graphitic phyllite with the highest carbon content is indicated on the Patate-Puyo map, but it does not contain enough graphite to be considered for industrial use.

5.2.6 Marble: The black marble band west of Baños has no commercial potential due to its apparent thinness.

5.2.7 Ornamental stone: The pyrite concretion in a loose block in the Topo River (see 5.1.5) could have value for collectors or tourist sales.

5.2.8 Talc: Mirror-like (slickensided) talcose surfaces are noted in the Peltetec Ophiolite.

5.2.9 Tourmaline: Black tourmaline crystals (schorl) up to 3 cm long form in pegmatites related to the Azafrán "monzonite". They are not translucent and are not suitable for the jewellery industry, but better specimens may exist.

5.3 Construction materials

5.3.1 Ballast: There is a quarry in the Azafrán monzonite where the material is used for ballast.

5.3.2 Slate: There are slates that can be used for roofing 4 km west of Baños.

5.3.3 Gravel: Weathered Abitagua granite is used as a gravel quarry.

5.4 Hot springs

The hot springs of Baños are well known and form a tourist attraction.

Those at El Placer are unknown and comprise a small spring with salt deposits over the regional granite (with blue quartz), which is highly altered by the waters.

6. RECOMMENDATIONS

For the second phase of the Project (1987), it is possible to return to three zones of economic interest:

- (1) Río Verde: metamorphic complex with dioritic and monzonitic bodies with Au (gold) and Cu (copper) mineralization.
- (2) Peltetec: an ophiolitic body with Cu and asbestos mineralization, and potential for Ni (nickel), Cr (chromium), Co (cobalt), Pt (platinum), Fe (iron), and Mn (manganese) mineralization.
- (3) Laguna Verde: a tectonically controlled quartz vein zone carrying Pb (lead), Ag (silver), and Cu mineralization.

The crossing to Huamboya could also be continued to complete the section and investigate the occurrence of fuchsite.



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Dr. Martin Litherland

Ing. Ramiro Bermúdez

CORDILLERA REAL PROJECT

ATTACHED: Location map of the sections
 Structural-geological map (2)
 Petrological sampling location map (2)
 Geochemical sampling location map (2)

No. 4403

QUITO, SEPTEMBER 30, 1986

TO : GERENTE TÉCNICO

FROM : ING. RAMIRO BERMÚDEZ and DR. MARTIN LITHERLAND

SUBJECT : Technical Report of the commission carried out to Guamote-Macas from August 1 to 17, 1986.

SUMMARY:

The Geological Research Project of the Cordillera Real, which is being carried out with the technical cooperation of the British Mission, conducted this commission in order to continue with the sections established in the annual schedule of activities; thus, section 7, belonging to the Guamote-Macas geotraverse, was 100% completed.

The Laguna Negra-9 de Octubre crossing was coordinated with the team that has been working on the geological survey of Sheet No. 90 Macas, Ings. Marco Marín (INEMIN) and Ivan Verset (Belgian Mission); this constitutes an effective way to jointly execute the sections with the teams working in the field, with adequate coordination and without duplicating physical or material efforts.

The objective of this section was the study of the metamorphic and igneous rocks of the Cordillera, both in their geological-structural aspect and in an initial exploration of the mineral potential of these rocks.

The Laguna Negra-9 de Octubre crossing was fully completed (approximately 35 km), between the two ends of the Atillo-9 de Octubre road.

Forty-five (45) samples were collected for petrographic study, and thirty (30) for geochemistry, with sixteen (16) belonging to stream sediments and fourteen (14) to heavy minerals.

Additionally, from September 10 to 13, an inspection reconnaissance was carried out on the occasion of the visit to the country by the Regional Head for Latin America, Dr. Clive Jones, during which outcrops considered relevant by the project were visited, given the geological-structural and mineralogical context they present (Peltetec-Huarguallá ophiolitic sequence, etc.). This short trip was accompanied by Ings. Edgar Salazar and Wilson Santamaría, directors of INEMIN.

1. INTRODUCTION**1.1 Objective**



To continue the study of metamorphic, semi-metamorphic, and igneous rocks of the Cordillera Real through programmed cross-sections (transects).

1.2. Assigned personnel

Brigade No. 1, composed of:

Ing. Ramiro Bermúdez	(INEMIN)
Dr. Martin Litherland	(ODA)
Sr. Alfonso Vaca	(INEMIN, vehicle driving and maintenance)

A Jeep Land Rover AT-0068 belonging to the mission was used as the means of transport.

1.3 Geographical aspects

1.3.1 Location: Section 7 (Guamote-Macas) is located southeast of the capital, approximately 200 km away, between the provinces of Chimborazo and Morona Santiago.

It is framed within the following coordinates:

Longitude	:	78° 45'	y	78° 05'	W
Latitude	:	01° 50'	y	02° 20'	S

1.3.2 Climate and vegetation: These two parameters are directly related to the elevations of the area.

From west to east, elevations fluctuate from ± 3080 mamsl (Guamote) to ± 3650 mamsl (Laguna Negra), with a temperate Andean to cold sub-Andean climate; characterized by precipitation, winds, and near-constant cold in the high-altitude zone during this season. The foothills of the Cordillera Real down to the plains are found at elevations fluctuating between ± 3000 mamsl (Achillán) and ± 1200 mamsl (Macas), with a temperate to subtropical climate.

The vegetation in these sectors is climate-dependent, as follows: in the highlands - páramo - there are grasslands (*pajonales*) and scrublands (*chaparros*), where strong winds and near-constant rains occur. Potato and barley crops are grown in the lower zones.

The subtropical zone is covered by subtropical forests, in addition to the presence of fruit orchards.

1.3.3 Hydrography: The main hydrographic axes in the current cross-section are the Cebadas and Upano rivers.

The Cebadas River flows from south to north; along its course, it joins the Guamote River (Huertapamba sector), and at the boundary of the Guamote and Riobamba map sheets, it takes the name Chambo River (LACMO sector).

The Upano River flows from west to east and, together with the Abanico River, constitutes the main hydrographic axes in the Zúñac-Macas sector.

1.3.4 Population: The inhabitants of these sectors, including the indigenous communities of Colay, Peña Blanca, and Atillo (± 3500 mamsl), are dedicated to agricultural work, livestock, and grazing, which for the most part is still carried out in a rudimentary manner. Occasionally, they also engage in fishing. In the foothill zones of the Cordillera Real, there are human settlements: Zúñac (± 2730 mamsl), Purshi (± 2720 mamsl), Playas (± 2310 mamsl), San Vicente (± 2350 mamsl), and 9 de Octubre (± 1350 mamsl), which are dedicated to agriculture and livestock and are mostly comprised of settlers (*colonos*).

1.7 Roadways: The South Pan-American Highway (Quito-Riobamba-Guamote) constitutes the link to the area (± 200 km/4 hours).

The trip toward Atillo (± 60 km/4 hours) from the turn-off in Guamote (Surtidor) is made via a secondary road which, for most of the journey, is in poor condition-muddy, narrow, and with a layout that makes it very long.

From Atillo to Laguna Negra (± 3600 mamsl), the journey is made via the new road under construction, the El Atillo-9 de Octubre road, which is currently stalled at the lagoon due to inclement weather preventing further progress.

From Laguna Negra (± 3600 mamsl), whose approximate distance is 35 km, it is connected via a trail or bridle path that is muddy and rugged.

El Retiro is connected to Macas by the new road under construction, the end of which is located right at the Quebrada El Retiro (± 45 km).

Toward Macas, the only land route used is via Cuenca (± 160 km), a road that is in poor condition in the Limón Indanza-Gualaceo section.

By air, through TAME, there are only 2 flights per week (Monday and Friday). There are light aircraft that fly regularly from Macas to Cuenca and Shell. Currently, Macas is "isolated" due to the lack of land routes that connect it in an agile and short way; with this sector of the Ecuadorian Oriente, unfortunately, neither the Puyo-Macas road nor the Guamote-Macas road - semi-stalled for various reasons - will be in service in the short term. Therefore, we will have to continue using the only route in service: Quito-Cuenca-Macas (± 650 km).

1.3.6 Land use: A high percentage of the soils in this zone are dedicated to agricultural and livestock activities.



The area of the Lagunas Atillo, Negra, Cuyo with its exotic and little-known landscape, will become accessible to national and foreign tourists with the construction of the new Atillo-9 de Octubre road and adequate tourism infrastructure.

Forest resources represent an important economic reserve in the area; it is necessary to rationalize their indiscriminate exploitation, which threatens the ecology of the zone.

1.3.7 Industries: Agricultural and livestock resources constitute an important source for the development and progress of these areas. If they are also provided with good communication routes, all agricultural products, meat, milk, and fruits would be distributed for consumption in the rest of the country.

Tourism would be another important source of income, as the sector crosses the Cordillera and descends to the eastern zone, featuring climatic and landscape changes that would be an attraction for national and international tourism. Therefore, the progress of the road Atillo-9 de Octubre, which will link these two regions of the country (Suroriente), is essential.

1.4 Previous works

Sauer W. (1965), performed a detailed description of the geology of: Cebadas-Paso de Colay-Macas (pages 38, 39).

The engineers Marco Marín and Ivan Verset (1986), performed a preliminary reconnaissance of the Macas-9 de Octubre zone (Commission Report, Macas Sheet).

1.5 Work methodology

The following cartographic sheets were used:

- Topographic sheets of: Guamote, Palmira, and Totoras, scale 1:50000, edited by the Instituto Geográfico Militar (Military Geographic Institute)
- Planimetric sheets of: Zúñac and Macas, scale 1:50000, prepared by the IGM for the Population and Housing Census of November 1973
- Aerial photographs covering the zone, scale 1:60000, provided by the team performing the survey of the Macas Sheet

The following methodology was employed:

- “In situ” geological observations
- Structural analysis (Study of structures)
- Sample collection for petrological study (45)
- Sampling of heavy sediments (14) and fluvial sediments (16)

1.6 Geomorphology

Geomorphologically, the investigated area contains:

- Zones with steep slopes and deep ravines that make ascent and descent difficult (Colay-Atillo-Laguna Negra).
- Zones with moderate slopes that constitute the foothills of the Cordillera Real (Galgán-Tambillo-Achillán).
- And finally, the plains zone with gentle slopes, which forms part of the Amazon basin.

2. LITHOLOGY

2.1 Introduction

This description of Section 7 (Guamote-Macas) includes a traverse through the Huarguallá Valley, which was carried out in search of the continuation of the Peltetec ophiolite (Licto-Huamboya). It also includes geological observations made in the Huarguallá and Guamote-Atillo sectors by the group of geologists accompanying Dr. C. R. Jones (BGS/ODA) during the inspection visit (September 10-13). They were: Drs. Litherland and Aspden (BGS/ODA), Ings. Salazar, Santamaría, Bermúdez and Viteri (INEMIN), and Ing. Pablo Duque (EPN).

2.2 Metamorphic Complex

For descriptive convenience, this will be presented in an east-to-west direction along the Guamote-Macas geo-traverse, as these are zones with an Andean strike (structural trend) that share a common lithology and metamorphic/structural history.

2.2.1 The Guamote-Cebadas zone (“molassic”): The outcrops consist of massive, red and pale orthoquartzites, originally fine- to medium-grained, interbedded with low-grade metamorphic metasiltsstones of red, purple, pale green, and pale grey colour. This may represent a molassic sequence.

2.2.2 The Huarguallá-Río Cebadas zone (“pelagic”): This zone comprises graphitic phyllites and fine-grained black and grey quartzites.



2.2.3 The Huarguallá-Río Cebadas zone (“oceanic”): Through this narrow sector, the Peltetec and Huarguallá serpentinites and gabbros outcropping are associated with green metalavas (basaltic?) and pale metalavas of probable spillitic origin.

There are also fine silicified red, green, and black metasediments of the chert or “umber” type, and others that are more pelitic with a purple-red colour. Tectonic segments in Huarguallá also show pale orthoquartzites, and others of a turbiditic type with sedimentary breccias composed of black clay fragments associated with graphitic phyllites and carbonaceous chert (“lyddite”). A block of dark limestone was observed.

Additionally, in both sectors, there are tectonic sequences of protomylonitized granite with blue quartz and smoky-coloured feldspar, which may originate from the metamorphic basement.

The Huarguallá ophiolite outcrops in the walls of the irrigation canal opened a few months ago. Structurally, the serpentinites follow above the tectonic segment of the “granitic basement”. They comprise a thickness of around 20 m, with more than 5 m of asbestiform-serpentine at the base and about 5 m of gabbro/metalava toward the top.

The ophiolite was not observed south of the Cebadas River, but a rounded block was seen in the Pancún Ravine.

2.2.4 The Colay (Río Cebadas)-Purshi (Río Upano) zone (“island-arc”): In this sector, graded greywackes and green metalavas outcrop in the Huarguallá River, along with greywackes, orthoquartzites, and graphitic phyllites as far as Colay. Further east along the Laguna Atillo-Purshi section, green metalavas outcrop again, associated with pale and green cherts. Following the Upano River to the east, there are blocks of pale-green metalava with banded metatuffs, followed toward the Purshi sector by fine-grained black and green quartzites with green and graphitic phyllites.

2.2.5 The Zúñac zone (“metamorphic core”): In the Zúñac-Playas River sector, the highest-grade metasedimentary rocks of the geo-traverse outcrop. These include muscovite schists and quartzites, in some places graphitic and garnetiferous or biotitic; and in others, biotitic and garnetiferous quartz-feldspathic gneisses. There are also rounded blocks of amphibolite and gneisses with blue quartz.

2.2.6 The Quebrada San Francisco-Río Abanico zone: This is a sector of metasedimentary and metavolcanic rocks. The first part as far as the Quebrada El Retiro is dominated by graphitic and quartzose schists and phyllites. Then, as far as the Abanico River, a mixed sequence of graphitic schists/phyllites, pelitic rocks, and talcose minors follows, with metalavas and banded metatuffs of felsic appearance, greywacke-type quartzites with blue quartz clasts, ferruginous red quartzites, and fine-grained, massive or phyllitic black metasediments containing iron and possibly manganese.

If the “metagreywacke” with blue quartz (and copper) is taken as a marker horizon, a symmetry emerges in the other Formations by means of conjectured axial traces of D1 (see map). Although this interpretation is very provisional, it is worth noting that this sector of the Metamorphic Complex is the first where (in this Project) the possibility exists to construct a pre-metamorphic stratigraphic column.

2.3 Igneous rocks and veins

2.3.1 Plutonic rocks: A large plutonic complex exists south of the highway between the Abanico and Salado Grande rivers. The rounded blocks in these rivers, and in the rivers (Colimbo and Salado Chico) and ravines between Abanico and Salado Grande, are dominated by “hornblende monzonites” with low quartz content and minor biotitic diorites and gabbros. In the Colimbo River, there is a block that appears to be ultrabasic. The large monzonite blocks are not deformed and contain mafic xenoliths of dolerite, diorite, and gabbro. It is possible that the dolerite outcrop seen on the highway represents the northern end of the plutonic complex.

Monzonite blocks west of Purshi are probably derived from the Quaternary tills and come from the summit of the Cordillera.

There are outcrops and rounded blocks of granodiorite in the area of the Cebadas River, and an outcrop of foliated granodiorite in the Laguna Atillo-Macas sector.

Near the granodiorite outcrop (mentioned above), there is a coarse-grained quartz-feldspathic acid rock without mafic minerals, which corresponds to an aplogranite.

2.3.2 Fine-grained igneous intrusives: In the sector from San Vicente to the Abanico River, there are minor fine-grained intrusives that cut across the last penetrative foliation in the Metamorphic Complex. Most are subvertical dykes up to 5 m thick, but there are subhorizontal bodies up to 20 m thick (see the occurrence of citrine on the map). Most of the intrusions are of microfeldspathic composition with little quartz or mafic minerals. There are also microgranites and quartz or biotite porphyries.

Microfeldspathic dykes are also found near Guamote.

2.3.3 Pegmatites: Near the Cugusha River, there are small quartz-feldspathic pegmatites related to the margins of microfeldspathic dykes and schistose xenoliths within the horizontal microfeldspathic intrusion.

Along the road near the Abanico River, there are pegmatitic pockets up to 20 cm long within the “metagreywacke”. There is tourmaline, barite? and copper sulphides in the pockets.

2.3.4 Veins: Calcite veins are prominent in the “oceanic” zone through Huarguallá, especially associated with the spillitic metalavas, where there are loose blocks of calcite crystals up to 30×20×20 cm in size.



There are also small calcite veins in the green metalavas of Laguna Atillo and in the ferruginous rocks further east.

Quartz veins are prominent in many lithologies of the Metamorphic Complex. In most cases, the veins follow the first schistosity (S1), but in certain places, veins following S2 or veins ptigmatically folded by D2 are noted.

3. STRUCTURE AND METAMORPHISM

At the extreme west of the geo-traverse, the “molassic” rocks of Guamote-Cebadas are of very low metamorphic grade. They primarily demonstrate isoclinal to tight D1 folds with a penetrative cleavage parallel to the layers in gentle attitudes, refolded by gentle to open D2 folds with crenulation cleavage in pelitic rocks with a 70° strike.

This pattern (planar zone of trans-Andean S1 and S2) continues to the east until the oceanic zone of Huarguallá, where S1 is subvertical and S2 has an Andean strike.

Further east, the low metamorphic grade continues in the metalavas of Laguna Atillo, where there is an extensive shear zone that forms tectonic lenses in the lavas and cherts. This zone is very prominent in aerial photographs, and the associated foliation has a westward dip. However, the zone does not demarcate a change in lithology or metamorphic grade and can be interpreted as a horizontal movement.

The most marked change in metamorphic grade occurs west of Purshi, where outcrops of schists and minor gneisses begin, containing metamorphic minerals such as biotite and garnet. It is probable that the dividing line is tectonic and represents the continuation of the Baños Front from the north, and that the higher-grade rocks represent the complex metamorphic core of the Cordillera Real.

East of San Francisco, the Metamorphic Complex is of low metamorphic grade and marked by two penetrative cleavages (S1 and S2) and zones of interference with D3 which carries a crenulation cleavage (S3). For the most part of the sector, S1 and S2 are subparallel and axial planar to the possible D1 folds drawn on the map. These folds, if they exist, must be vertical and tight with gentle plunges (probably to the south). However, along the Abanico River, S1 is gentler and folded by subvertical S2, indicating that the D1 folds/structures change from vertical to horizontal toward the east in this sector. Along the Abanico River, there are faults (“slides”) along the flanks of D2 folds.

4. CORRELATION AND INTERPRETATION

To the west of the geo-traverse, one can interpret a multiple collision zone with ophiolites and the forearc through Huarguallá, passing eastward to an island-arc or continental-arc zone as far as the “metamorphic core”, which may represent the continent. This collision zone is cut by intrusives approximately 70 Ma in age (Hall and Calle, 1982) and also features horizontal movement zones, as noted near Atillo.

To the east, a supracrustal sequence outcrops, which could be a back-arc basin or a marginal basin. It is possible that this sequence continues as far as Macas and is related to the Jurassic-age Santiago Formation.

5. ECONOMIC GEOLOGY

5.1 Metallic minerals

5.1.1 Gold: A few grains of gold were found in panning in the Upano, Playas, and Abanico rivers and in the Pancún Ravine. Indigenous people say that gold is washed further upstream in the Abanico River. It is not yet possible to speak of the gold potential of the area, but there is a possibility that the monzonitic plutonic complex in the east of the cross-section is analogous to the auriferous (gold-bearing) granite of Zamora in terms of lithology, age, and intrusive form.

A sample taken by I. Verset (Belgian Mission) of “metagreywacke” with chalcopryite mineralization south of the Quebrada El Retiro contains traces of gold determined by chemical analysis.

5.1.2 Copper, Zinc and sulphides: In the Huarguallá serpentinite, there are small veins of chalcopryite? altered to malachite.

Also in the same sector, there are indications of chalcopryite associated with black shale xenoliths in calcite veins that cut across the spillitic metalavas.

Further north in the Peltetec ophiolite, a small vein ($\pm$ 3 cm) of sphalerite (blende) was found in the zone where copper mineralizations had been observed.

In the green metalavas of Laguna Atillo, there are small indications of chalcopryite associated with pyrite.

There are quartz veins up to 50 cm wide along S1 that carry pyrite, chalcopryite, and bornite within the fine-grained ferruginous rocks in the Abanico River.

The four occurrences of “metagreywacke” with clastic blue quartz carry traces of chalcopryite with pyrite along quartz diffusion veinlets or within the rock mass, which can contain up to 5% iron sulphides.

This Formation is the most notable lithology due to the sulphide content in the San Francisco-Macas sector, although there are other lithologies (ferruginous, graphitic, and metavolcanic rocks) that also carry significant pyrite. It is probable that the “metagreywacke” Formation has syngenetic “stratabound” type mineralization, which may be concentrated by tectonic zones such as fold hinges (noses).

5.1.3 Iron and manganese: There are two sectors where fine-grained, black/brown rocks with a ferruginous appearance occur. In the west, within the “oceanic” zone, there are rocks of this class associated with cherts and lavas that have the appearance of “umbers”.



In the east, the ferruginous rocks form part of the supracrustal sequence of a marginal basin? The ferruginous Formations could have thicknesses of up to one kilometre (see structural interpretation on the map) and could carry manganese. Samples taken for chemical analysis have a limolitic (silty) content and lack economic potential, but there may be sectors where the metallic content is more concentrated.

In the white cherts near Laguna Negra, there are manganiferous bands of one or two millimetres associated with pyrite and siderite.

5.1.4 Magnesium: In the Huarguallá serpentinite, there are magnesite veinlets, some with euhedral and translucent crystallites up to 1 cm long.

There are talc schists near the Cugusha River (see Talc).

5.2 Industrial rocks and non-metallic minerals

5.2.1 Clay: Near the Cugusha River (by the highway) and other nearby locations, there are Quaternary clays up to 2 m thick. Samples have been sent to the Non-Metallic Project for analysis.

5.2.2 Asbestos: Chrysotile asbestos is well-developed in the Huarguallá serpentinite. At the lowest structural levels, for about 5 m of thickness, the asbestos forms in fibres (“slip fibres”) parallel to tectonic movement planes within the serpentinite. These planes have a separation of 1 to 3 mm and are thicker toward the top. Further up, the serpentinite (ca. 5 m) is more massive, and the asbestos forms a “stockwork” through fractures that separate serpentinite blocks up to 20×10×10 cm in size. In the veinlets, the asbestos forms “slip fibres” in the shape of pale-green masses up to 7×2×1.5 cm in size. In the veinlets, the asbestos is associated with magnesite.

In Riobamba (one hour from Huarguallá), there is a factory that uses imported asbestos to manufacture pipes. The Huarguallá occurrence could be studied as an alternative source. Samples have been sent to the Non-Metallic Project for studies.

5.2.3 Carbonates: Calcite veins are prominent in the spillitic metalavas throughout the Huarguallá area. There are blocks of milky calcite crystals up to 30 × 20 × 20 cm in size, which break into smaller individual crystals with a hammer blow.

To the NE of Huarguallá, in the Alao Valley, there is a concession reportedly mining calcite veins for carbonates.

A single block of limestone (marble) was found in the Huarguallá section. The rock is dark grey and fine-grained.

In some parts of the Huarguallá section, there are travertine layers 1 cm thick covering newly exposed rocks.

5.2.4 Citrine quartz: Small crystals of citrine (yellow-coloured quartz) are observed in pegmatites associated with microfeldspathic intrusives.

5.2.5 Feldspar: The minor microfeldspathic intrusions contain almost pure fine-grained feldspar. Most are altered, but there is one relatively fresh dike (see “feldspar” on the map).

5.2.6 Graphite: Phyllites and schists with graphite are common along the geotraverse. Outcrops with the highest carbon content occur in the Huarguallá section in bands 1–2 m thick.

5.2.7 Ornamental stone: Huarguallá serpentinite blocks, which can be obtained in sizes up to 20 × 10 × 10 cm, could serve the local artisanal tourism industry for making ashtrays, figurines, ornaments, etc. The serpentinite is very attractive, black in colour with green-yellow spots.

There are rounded “gabbro” boulders in the Río Salado Grande with black hornblende megacrystals up to 1 cm long within a medium-grained hornblende-feldspar matrix. The hornblende cleavage planes are shiny. This stone could serve as cladding for building facades.

5.2.8 Talc: Near the Río Cugusha along the road, there are bands up to 2 m thick of a white schist of talcose material within pelitic schists. Samples have been sent to the Non-Metallic Project to identify the material (which may be fine sericite).

5.2.9 Tourmaline: Near the Río Abanico along the road, there are pegmatitic pockets up to 20 cm long within quartzite, containing a feldspar zone at the margins and black tourmaline (schorl) inside, intergrown with pyrite and barite?

6. RECOMMENDATIONS

6.1 Detailed studies of ophiolitic/oceanic rocks

The identification of an ophiolite zone and associated oceanic sediments in the Peltetec-Huarguallá-Río Cebadas area will have both geological and economic importance. Despite the observations noted during the traverses and the indices of copper, zinc, magnesium, and asbestos—along with a nickel geochemical anomaly (Peltetec)—there are also possibilities of finding chromium, manganese, and rarer metals such as platinum.

The Project will execute detailed studies next year (1987), after completing this diagnostic stage and analysing the 1986 results and prospecting methods used in other parts of the world.

6.2 Detailed studies of the Oriental basin and associated plutons



Along the traverse from Quebrada El Retiro to Macas, a metamorphic-plutonic complex has been noted with signs of mineralization that deserve more detailed study. The metamorphic rocks belong to a volcano-sedimentary basin with sulphide mineralization (including chalcopyrite) in “stratabound” form, as well as ferruginous and possibly manganiferous formations.

The intrusions cutting through the complex vary from ultrabasics (gabbro/dolerite), diorite, monzonite, and granodiorite to aplogranite and pegmatites, and they may carry their own mineralization.

7. REFERENCES

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Dr. Martin Litherland

Ing. Ramiro Bermúdez

CORDILLERA REAL PROJECT

ATTACH. Structural geological map (2)
 Petrological sampling location map (2)
 Geochemical sampling location map (2)

No. 5042

QUITO, NOVEMBER 11, 1986

TO : GERENTE TÉCNICO

FROM : ING. FRANCISCO VITERI and DR. JOHN ASPDEN
CORDILLERA REAL PROJECT

SUBJECT : Technical Report of the field commission to Paute, Amaluza, Méndez, and Alausí; Osogochi and Palmira; conducted from September 29 to October 15, 1986

SUMMARY:

The geological and geochemical research works corresponding to this commission pertain to the completion of Section No. 8 (Cuenca, Méndez, Gral. Plaza, Gualaceo) in its northern sector. This section began from the town of El Descanso (Paute), passing through Amaluza until reaching Méndez by foot traverse, within the metamorphic belt of the Cordillera Real.

Parallel to the geological research study, geochemical sampling of stream sediments and heavy minerals was carried out in the drainages of interest, as well as petrographic sampling in significant outcrops.

Furthermore, a geological reconnaissance was conducted through the sectors of Alausí, Zula (Totoras), and Palmira; Azogues, Pindilig, and Cañar-Ingapirca, with the purpose of locating evidence of ophiolitic complexes situated further north (Litherland, Bermúdez, 1986).

The towns of Paute and Amaluza belong to the province of Azuay, while Guarumales and Méndez are under the jurisdiction of Morona Santiago, thus forming the study axis of this commission, located in the southern Sierra and the Amazon region, respectively.

Altitudes vary considerably; consequently, the climatology of each sector is not uniform. Paute has an altitude of 1940 mamsl, reaching 1600 mamsl at Guarumales, and finally Méndez with an altitude of 1000 mamsl.



Within the geological framework, the investigation area is represented from west to east by metavolcanics (Paute Series?), followed by a predominance of pelitic rocks, then passing into intrusive rocks belonging to the Amaluza granodiorite (Kennerley, 1980), followed by psammitic and pelitic rocks of the Metamorphic Complex, and finally the Cretaceous sedimentary rock series.

Within the pelitic sequence (especially phyllites), there is a significant presence of graphite, as well as Fe minerals in alteration; quartz has frequently been observed in the form of lenses.

The psammitic rocks (mainly quartzites) present a very fine-grained texture with a logical predominance of quartz and, in some cases, weak foliation.

Further west, an intercalation of psammitic and pelitic rocks can be observed, mainly phyllites and schists with pyrite-along with metavolcanic boulders in the main creeks.

Finally, very close to Méndez, we can already visualize the Cretaceous sedimentary sequence, mainly limestones with fossils intercalated with graphitic phyllites (Napo Fm.), followed by sandstones with ripple marks from the Hollín Fm.?

Regarding economic geology, there is information on the presence of alluvial gold in the main creeks that flow into the left bank of the Paute River. A massive sulphide concentration? was located in the town of Guarumales, containing abundant pyrite and copper minerals; much gold panning has been performed, finding minerals, primarily traces of iron and copper.

1. INTRODUCTION

1.1 Objectives

During this commission, published geological sheets of Azogues and Cañar were traversed, as well as the Sucúa and Méndez quadrangles (where no information exists), at a 1:100000 scale. This fulfilled the objectives proposed in previous technical reports: the determination of regional geology, structure, and mineralizations associated with the metamorphic complex of the Cordillera Real. These studies are being carried out with technical assistance from the British Government.

Subsequently, geological reconnaissance traverses were made through Alausí, Osogochi, Palmira, and from Cañar to Ingapirca, with the sole objective of locating further south any evidence of ophiolites reported by previous commissions conducted by the Cordillera Real Project.

1.2. Assigned personnel

The commission was composed of:

Ing. Francisco Viteri S.	INEMIN
Dr. John Aspden	ODA
Sr. Kerley Jurado	Driver/INEMIN

The mission was carried out from September 29 to October 15, 1986.

1.3 Geographical and human characteristics

The investigation area is located in the south of the country, locally to the northeast of the city of Cuenca. Access from Paute to Guarumales is good; however, there is a traverse that must be done on foot to reach Méndez, covering approximately 50 km. Topographically, it belongs to the sub-Andean region situated on the eastern flank of the Cordillera Real, and part of the southern sector of the Cordillera de Allauquiru. The section was mapped following the right bank of the Paute River, which is the main hydrographic network in the area.

The climatology and vegetation are varied. There are two well-differentiated climate types: the cold of the Andean region (highlands) and the temperate climate of the sub-Andean region. In the lowlands (Méndez, Patuca), there is a predominance of a humid tropical climate with average temperatures of 30°C.

The vegetation is varied and extensive, with a great variety of timber and fruit trees; the livestock industry is also widely developed.

The region contains a project of national importance: the Paute Hydroelectric Project, which generates electricity for a large portion of the national territory. This has partially aided the settlement of colonists in sectors of the study region.

There is small-scale mining activity dedicated to the exploitation of alluvial gold.

The drainage within the investigation area is formed by the Paute and Negro rivers, whose waters reach the Upano; it is then called the Namangoza River. This entire system constitutes the upper watershed of the Santiago River Basin, a main tributary of the Marañón, which flows into the Atlantic under the name of the Amazon.

1.4 Previous works

Within the investigation area, few geological works have been conducted at a local scale, with only the following regional-type studies existing:

- Geología del Ecuador by W. Sauer (1965)
- Geological Map by Baldock (1982)
- Azogues Geological Sheet by Bristow (1972)



1.5 Work methodology

- Compilation of existing geological information.
- Field verifications, road surveys, and foot traverses.
- The geological-structural mapping was conducted through systematic itineraries during which petrographic samples were collected at 86 sampling points, as well as 39 stream sediment samples and 10 heavy mineral samples. These will be analyzed in the laboratory following their respective macroscopic examination.
- For the preparation of the Outcrop (Geological) and sampling point maps, the topographic sheets of Azogues, Guachapala, and Cola de San Pablo were used, along with planimetric maps of Galápagos and Méndez, all at an approximate scale of 1:50000.

1.6 Geomorphology

Geomorphologically, two large typical landscapes are found along a transverse profile of the studied sector: the Andean region and the Sub-Andean region. The latter begins approximately from the headwaters of the Paute River and part of the Amazon region, consisting of a large narrow valley in the southern sector of the Upano River.

The Cordillera Real located in the study region is the highest and most irregular, consisting of a Palaeozoic core of metamorphic rocks covered by recent volcanic rocks (Tarqui Fm.) and interrupted by small plutons (e.g., the Amaluza pluton), possibly associated with fault zones and the Amazon region where mainly Cretaceous sedimentary deposits are found, largely covered by Quaternary sediments.

2. GEOLOGY

As in the case of previous traverses carried out by the Cordillera Real Project, it should be noted that the following interpretation is preliminary and may be modified in the future. At the time of writing this report, thin sections are not available; therefore, the nomenclature of various rock types is based solely on the macroscopic identification of the available samples.

The only local geological study in the investigation area was conducted by Bristow et al., who carried out geological mapping at a 1:100000 scale between Paute to the west and Guarumales to the east. Their findings have rarely been included in the published geological sheets of Cañar and Azogues. The eastern section of the traverse, from Guarumales to Méndez, has not been previously mapped, and a sketch of the area's geology is presented here for the first time.

The various lithostratigraphic units recognized are described below. It should be noted that the younger Quaternary deposits present, particularly in the Paute area, are not described in this report.

3.1 Paute Series

Name originally given by Bristow et al. (1980) to describe the metavolcanic and metasedimentary rocks that outcrop approximately between Paute in the west and Amaluza in the east. The metavolcanic unit is named the San Francisco metavolcanics, and the metasedimentary unit as the El Pan Schists. These names will be used here for convenience.

3.1.1 San Francisco metavolcanics

This unit basically consists of altered volcanics of a dirty-green coloration, which include agglomerates, lavas, and tuffs. Some horizons may also contain poorly preserved pillow lavas. Additionally, minor metasedimentary horizons consisting mainly of green and black phyllites have been observed within the main volcanic outcrops; these finer units clearly demonstrate two phases of deformation.

The metavolcanics are considered to be composed of altered andesites, but toward the south of Paute, more mafic varieties may exist. Phenocrysts of both hornblende and feldspar have been found, especially in the agglomeratic types, which are common around the Paute area. The alterations apparently consist largely of chloritization and carbonatization; no fresh volcanic samples were found during this traverse.

The eastern contact with the El Pan Schists near Loma Nuñurcu was not seen. In any case, the presence of a high percentage of metavolcanic blocks along the road suggests that the more competent San Francisco unit could be separated from the less competent semipelitic sequence to the east by a major fault.

To the north, a sequence of metavolcanics is also exposed along the road to the west of the Amaluza Batholith; we consider these rocks to represent the northern continuation of the San Francisco metavolcanics. These rocks are often massive but also contain metasedimentary intercalations of phyllites, quartzites, and feldspathic quartzites. The southern limit of the sequence corresponds to the fault that crosses the road to Amaluza, approximately 1 km south of Quebrada San Isidro. This fault may partly control the trans-Andean strikes recorded in this area. Its eastern limit is assumed to correspond to a major regional fault, which separates the Paute Series from the older metamorphic rocks of the Cordillera Real. Emphasis should be placed on the fact that this fault was not seen in the field; however, in view of the different aspects of the rocks to the east and west of the Amaluza Batholith, and the information provided by the geotraverse carried out to the north, we consider it very likely that a major tectonic contact exists within the Amaluza area.



The main outcrop of the El Pan Schists also contains metavolcanic rocks, which are quite exposed in the Quebrada Honda. These rocks are similar to those found in the San Francisco unit, but their structural composition is uncertain.

3.1.2 El Pan Schists

This is a predominantly semipelitic sequence consisting of black phyllites, often graphitic; green feldspathic phyllites (volcanics?); calcareous phyllites; dirty black limestones; and quartzites. Quartz veins and segregations and pyrite are quite common throughout the sequence.

The El Pan Schists are cut by a series of felsite dikes and other minor intrusions, which have been deformed. Felsite phenocrysts exposed in the Quebrada de Ramos area may be composite, as they appear to have mafic margins.

Near the western contact with the San Francisco metavolcanics, a felsic infill is present, which forms Loma Nuñurcu. This infill is not deformed, and it is presumed to belong to the post-Mesozoic era.

3.2 Amaluza batholith

This intrusion is well exposed along the Amaluza-Guarumales road; in the sites where outcrops have been found, it appears to have a uniform composition, consisting of medium-grained tonalite, hornblende, and biotite with a uniform texture. Small mafic xenoliths were also observed.

According to Baldock (1982), the pluton has a K-Ar (Hornblende, Biotite) dating of 49 ± 2 Ma, and clearly intrudes both the Paute Series and the older metamorphic rocks to the east? It has a silicified hornfels margin, which contains disseminated pyrite and perhaps galena.

3.3 Guarumales-Yerbabuena Unit

At the moment, we will consider that the metamorphic rocks exposed approximately between Guarumales to the west and the Yerbabuena River to the east belong to the same lithostratigraphic unit. In any case, it should be noted that to the east of Guarumales, outcrops are sporadic; therefore, the division of this unit into lithological belts can only be considered approximate.

As mentioned previously, the eastern contact of this sequence with the Paute Series is considered to be a major regional fault, but the exact position of this fault remains uncertain. Immediately to the east of the Amaluza Batholith, the metamorphic rocks appear more highly deformed and may include mylonitic belts. Likewise, the presence of garnets and sillimanite could indicate that these rocks underwent a higher metamorphic grade than those of the Paute Series.

These observations will be checked once thin sections are available, but if the mylonites are confirmed, it would be logical to place the tectonic fault between the Paute Series and the Guarumales-Yerbabuena Unit to the east of the Amaluza Batholith, rather than where it is currently located along its eastern margin. Based on regional considerations, we believe this fault probably belongs to the Jurassic-Early Cretaceous period (Aspden et al., in press) and it is possible, therefore, that in this area it has been obscured by the younger Amaluza pluton.

Lithologically, the Guarumales-Yerbabuena unit consists of a variety of rock types, some of which require thin-section studies for positive identification. In the eastern extreme, quartzites, feldspathic quartzites, and partly graphitic phyllites are dominant. Minor volcanic horizons are also present to the west of Guarumales. To the north of the Cuilches River, a more massive sequence of metavolcanics is exposed; these rocks are quite similar to those of the San Francisco Unit to the west. As with many of the previous units, remnants of primary textures are still discernible in these rocks, and they may actually represent a fault lens of the San Francisco metavolcanics within the Guarumales-Yerbabuena unit. Elsewhere within the Guarumales-Yerbabuena unit, the rocks, with the exception of the phyllitic horizons, have a more schistose appearance.

East of Guarumales, quartz schists and black and green phyllites continue to be the dominant lithology, but the quartzose rocks often show a distinctive bluish colour. This sequence passes eastward into another consisting especially of pale green quartz-feldspathic schists, which are also associated with green and black phyllites. This belt is followed by a wide band of phyllites, and at the eastern end, another sequence of pale green schists is present. In the field, these latter rocks are known as green schists, and we suggest they are possibly derived from a volcanic matrix.

3.4 Jurassic sequence?

East of the Yerbabuena River, low-grade metamorphic rocks consisting mainly of phyllites are present. This belt is poorly exposed, and the presence of green schists within the belt may indicate that the contact with the Guarumales-Yerbabuena unit is complex.

Quartzose black phyllites exposed in the Yerbabuena River are lithologically identical to those present west of Macas (Litherland and Bermúdez, 1986); also, the presence of loose volcanic clasts in the Pescado River suggests these rocks may be of Jurassic age.



3.5 Napo sequence

The contact of the Napo sequence with the Jurassic rocks was not seen, but in a small river at La Margarita, breccia blocks were observed which appear to contain clasts from the Jurassic belt. This could be taken into account to represent the approximate contact between these two sequences. The Napo sequence is generally poorly exposed but consists predominantly of black or purple limestones, calcareous and non-calcareous phyllites, and siltstones. Fossiliferous blocks are quite common in the river float (alluvium), but unfortunately, none of them were found in situ. Toward Méndez, an outcrop is present on the side of a small road in a quarry, which consists of massive, light-brown cross-bedded quartzites; in the Ochansu River, fine-grained, dirty, purple-black quartzite is exposed. In the float blocks, fossiliferous calcareous limestones are often quite common. Toward the east-southeast of this point, no more exposures were seen, as the margins of the Paute Valley are entirely covered by terrace deposits at the junction of the Paute and Negro rivers; however, the Napo sequence reappears in the riverbed.

Despite the lack of exposed outcrops preventing a detailed structural interpretation of the Napo and Jurassic sequence, it appears these rocks dip moderately and uniformly to the west. A well-developed penetrative cleavage (S1?) is present in the Jurassic sequence; however, cleavages within the Napo sequence appear to be restricted and may be related to narrow tectonic zones (completely controlled?).

4. ECONOMIC GEOLOGY

At the time of writing the report, the analytical results of the stream sediment samples collected during the traverse are not available; despite this, the following information may be of interest, though some will require a more detailed subsequent study.

4.1 Graphite: This mineral is common in the El Pan schists as well as in the Guarumales-Yerbabuena unit. It is probably too fine-grained to be used commercially, but a sample from the Chalacay River has been sent to the German Mission.

4.2 Lead ± Molybdenum ± Zinc: Geochemical anomalies have been reported in Quebrada Pahuancay, Quebrada Jordán, Quebrada Jurupillos, and Quebrada Chontal by Bristow et al. (1980). Small amounts of lead have also been reported by the same authors, associated with the Amaluza Batholith at its eastern contact.

4.3 Copper/pyrite: Massive pyrite and chalcopyrite, along with bornite and minor galena, are found exposed near an almost vertical schistose/phyllitic sequence near Guarumales. Samples of this type have been sent to the INEMIN laboratories for gold and silver mineralization analysis. If the sample contains reasonable values of precious metals, then further studies will be conducted in the area.

In other sectors, pyrite is quite common, especially in the phyllitic rocks of the El Pan schists within the Guarumales-Yerbabuena sequence. Regardless, these occurrences are likely of little commercial value.

4.4 Gold: It was not found during panning, despite reports of gold occurrences in the Paute River and the fact that it is worked by local inhabitants. These alluvial areas are specified in the attached map.

5. REFERENCES

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Ing. Francisco Viteri

Dr. John Aspden

CORDILLERA REAL PROJECT

BRIGADE No. 2

ATTACH.

Geological map

Sediment and petrographic sampling map



No. 4017

QUITO, SEPTEMBER 24, 1986

TO : GERENTE TÉCNICO

FROM : ING. FRANCISCO VITERI and DR. JOHN ASPDEN
CORDILLERA REAL PROJECT

SUBJECT : Technical Report of the service commission to Nambija and Limón
(Gral. Plaza) – Gualaceo, carried out from August 6 to 22, 1986

SUMMARY:

The work carried out during this commission focused on Section No. 8, from the town of Limón (Gral. Plaza) to Gualaceo, within the metamorphic belt of the Cordillera Real (Geological Map, Baldock, 1982), and on a brief reconnaissance of the Nambija and Guaysimi areas.

The geological study (Limón-Gualaceo) was conducted along the road and through small traverses; parallel to this work, geochemical sampling of stream sediments and heavy minerals was carried out in the drainages of primary importance.

The areas of Gualaceo, belonging to Azuay, and Limón, belonging to Morona Santiago, form the study axis of this commission. These towns are located in the Sierra austral and the Sub-Andean region, respectively; Gualaceo is situated at 2200 meters above sea level (mamsl) and Limón (Gral. Plaza) at 1050 mamsl.

Within the geological framework, the investigation area is represented by rocks of the Metamorphic Complex, as well as intrusives and sedimentary rocks with incipient metamorphism (Napo Fm.?), in addition to Cretaceous and recent volcanic rocks.

The Metamorphic Complex may correspond to the Zamora Series, consisting of phyllites, slates, schists, and quartzites. Within this section, it was observed that this Complex is intruded by rocks of the tonalite and diorite types, with a predominance of hornblende. See Map No. 1.

The sediments (Napo Fm.?) located to the east, very near the town of Plan de Milagro, are low-grade metamorphosed. These sediments consist of black limestones with calcite veinlets and phyllites; fossils can be observed within this assemblage.

The volcanic rocks have been located in the western part of the section; they are partially metamorphosed and tectonized with disseminated pyrite, belonging to the Cretaceous Paute Group.

The Tarqui Formation (Pleistocene), consisting of tuffs and conglomerates, has covered a significant portion of the older rocks.

Regarding economic geology, it can be stated that there are few indications of metallic and non-metallic minerals.

1. INTRODUCTION

1.1 Objectives

The geological research study of the metamorphic belt of the Cordillera Real, which is being carried out with technical assistance from the British Government, has the basic objective of determining the regional and local geology, structure, and mineralization associated with this metamorphic complex. Jointly, geochemical sampling of stream sediments, heavy minerals, and rocks was conducted.

Within this commission, a large part of the Azogues geological sheet (already published) has been covered, as well as part of the Sigsig and Méndez sheets currently under study, all at a scale of 1:100000.

1.2. Assigned personnel

The commission was composed of:

Ing. Francisco Viteri	INEMIN
Dr. John Aspden	ODA
Sr. Oscar Acosta	Driver/INEMIN

The work was carried out from August 6 to 22 of the current year (1986).

1.3 Geographical and human characteristics

The investigation area is located in the southern zone of the country, southeast of the city of Cuenca; accessibility is possible via a third-order road (classification according to MOP specifications).

Topographically, the eastern part of the section corresponds to the Sub-Andean region, situated between the foothills of the Cordillera Real and the Cordillera del Cutucú. Toward Gualaceo, the topography is Andean, with mountainous terrain and altitudes reaching up to 4300 mamsl (on the road).



The climatology and vegetation are varied; there are two main types of climate: cold Andean in the high zones and humid tropical in the low zones. The average annual temperature in the town of Limón is 19°C, while in Gualaceo, a temperate climate predominates. The vegetation consists of a wide variety of timber trees; in the higher parts, these decrease in size but maintain their density, and shrubs even increase.

Land cover is characterized by human intervention in the lower parts.

Mining activity is incipient; in Limón, there is the exploitation of silica sands for glass manufacturing, and in very few rivers, alluvial gold exists.

The drainage is mainly composed of the Paute, Yuganza (Culebrillas), and San Francisco rivers, whose waters reach the Namangoza, together constituting the upper watershed of the Santiago River hydrographic basin, a main tributary of the Marañón, which flows into the Atlantic Ocean under the name of the Amazon.

1.4 Previous works

- Geología del Ecuador by Walter Sauer (1965)
- National Geological Map by Baldock (1982)
- Azogues Geological Sheet (1980)
- Gualaceo-Gral. Plaza Section by Trouw (1976)

1.5 Work methodology

- Compilation of existing geological information
- Field verification, roadside survey
- Rock, stream sediment, and heavy mineral sampling, taking 45 petrographic samples, 19 stream sediment samples, and 4 heavy mineral samples
- Preparation of the outcrop map of the studied section

1.6 Geomorphology

From a morphological standpoint, the geological-structural section can be divided into two areas or sectors: the East, with very irregular modelling forming a narrow valley along the Yuganza River, mostly covered by sedimentary deposits; and the West sector, belonging to the Cordillera Real, which is higher and more irregular, consisting of a Palaeozoic core of metamorphic rocks largely covered by recent volcanics (Tarqui Formation), whose foothills are interrupted by the presence of plutons likely associated with a fault zone.

2. GEOLOGY

The geological framework established along the road from Limón and Plan de Milagro to Gualaceo cuts from east to west through the metamorphic belt of the Cordillera, allowing for a clearer differentiation of units within this belt, as well as fault zones and intrusives. Within the section, it was possible to observe zones of low-grade metamorphism (to the east), a tectonized zone, pelitic and semi-pelitic units, small sectors of calco-magnesian rocks, and finally volcanic rocks of the Paute Group.

2.1 Plan de Milagro-Gualaceo

This geological mapping and geochemical sampling program were executed between August 11 and 22 along the main road that crosses the Cordillera Real, connecting the towns of Plan de Milagro to the east and Gualaceo to the west. Aerial photographs were available for a significant portion of this section, but many of these had been edited prior to the construction of most existing roads, whose positions, especially at the eastern end, can only be estimated. At the moment, thin sections of the collected rocks have not been obtained; therefore, part of the rock identification remains tentative. Likewise, geochemical analyses are not yet available, so comments regarding the economic potential of the area are also preliminary.

From east to west, the following rock types or lithostratigraphic units have been recognized.

2.1.1 Foliation of the argillites/slates

A thin belt (ca. 0.5-1 km) of foliation in low-grade argillites (slate) is exposed immediately west of Plan de Milagro. These rocks are highly altered and generally poorly exposed; however, poorly preserved fossils (gastropods?) were observed in one outcrop.

It is considered that these rocks represent sectors of the Napo Formation (or possibly the Tena Formation) which has been deformed and foliated due to the eastward thrusting of the older metamorphic rocks of the Cordillera Real. Only a penetrative cleavage was seen, and although variable, it tends to dip sharply to the east.

2.1.2 Metavolcanics / “Tectonic zone”

Immediately west of the foliated argillite, and likely separated from it by a major fault (NE-SW?), lies a massive sequence of felsic lava. These rocks are not well-exposed, but they are thought to be foliated and are considered to be of “pre-Napo” age (pre-Albian).



A second belt of highly altered felsic tuff, which may also include high-level intrusives and/or lavas, is also exposed toward the west. These rocks are tentatively correlated with those to the east, from which they are separated by what has been interpreted as a major tectonic zone. Some outcrops of the “eastern” volcanic belt are intensely sheared.

The “tectonic zone” separating the two felsic volcanic belts consists mainly of black phyllites and graphitic black phyllites, in addition to subordinate quartzites and possible amphibolites. The width of this zone is not known with precision as the road “line” is approximate; however, it is likely on the order of 2-3 km.

Within the tectonic zone, several outcrops consisting of mylonitic rocks have been observed. Emphasis should be placed on the need to verify the identification of these rocks through sectional studies, but at the moment, we must interpret this zone as one of great tectonic significance, in which we consider the separation of the ancient metamorphic rocks of the Cordillera Real from the younger rocks, essentially the post-metamorphic rocks of the “Oriente”.

2.1.3 Phyllitic belt

This belt, which together with the semipelitic belt (see next section) makes up the total of the “metamorphic rocks of the Cordillera”, begins approximately 1 km east of the first unnamed northern tributary of the south bank of the Ishpingo River. Precise relationships with the metavolcanic rocks to the east are not yet known; however, the fact that this sequence has clearly been subject to at least two episodes of strong deformation suggests that it may be of greater age.

The most common rock type is black phyllite, with or without graphite. Subordinate quartzites are also present, as well as green/grey phyllites which are likely of volcanoclastic origin.

2.1.4 Semipelitic belt

West of Ángel Sabio, the percentage of psammitic rock gradually increases, with a corresponding decrease in the amount of pelitic material. Minor amounts of green phyllites (volcanoclastic?) are also present. The increase in psammitic material is related to a facies change and a structural structure similar to the pelitic and semipelitic belts, suggesting that these rocks belong to the same lithostratigraphic unit and are of the same age.

In both belts, tight F2 folds are relatively common, and S2 is in many cases strongly developed. In the semipelitic sequence, structural dips are generally moderate to steep and toward the east, toward the “line”; however, there is a zone approximately 2-3 km wide where the dips tend to flatten and the S1 strikes are “trans-cordilleran”.

In this area, the F2 folds are quite exposed and gently inclined, but with trends toward the Cordillera. The eastern boundary of the semipelitic belt is poorly defined due to a lack of exposure, but the somewhat chaotic structural situation may possibly be related to major faulting or tectonism along the margin.

To the west of Zapote, small tonalitic and biotic intrusions are exposed within the semipelitic belt. Although this intrusion is altered in some sectors, it is generally fresh and appears to be undeformed. Some samples were collected for dating, but it is currently considered that this intrusion belongs to an age post-dating the metamorphism of the Cordillera.

To the east of Zapote, a narrow belt of schistose rocks of apparent low grade is present. These rocks are poorly exposed, and their relationship with the semipelitic belt is unknown.

In the Ishpingo River, where the belt is cut by the main road, float (boulders) of amphibolite and garnet-bearing amphibolite were found. Regardless, these rocks were not found in situ.

2.1.5 Phyllitic-schistose belt

On the eastern side of the line, there is a poorly exposed sequence of phyllites and schists, which seems to have undergone more intense deformation than the rocks to the east. This belt is composed of greenish quartzose phyllites and schistose rocks, some of which contain detrital blue quartz. Both the eastern and western boundaries are poorly defined, but at the moment they are considered tectonic, and the relationship of these rocks with respect to the rest of the Cordillera sequence is unknown.

2.1.6 Paute Group

Immediately west of the bridge crossing the Culebrillas River, deformed (foliated) green metavolcanics are exposed, which are believed to belong to the Paute Group. The contact with the rocks to the west is not exposed, but it is thought to be tectonic, with probable regional significance.

Along the main road, the Paute Group consists mainly of lavas, but also includes schistose felsic horizons and various sedimentary intercalations of quartzites, graphitic phyllites, and phyllites. Structural data show constant Cordilleran strikes; the dips are generally toward the west. Deformation simultaneously decreases notably in the same direction and, in the Palmas area west of the massive lavas and agglomeratic horizons, the Paute Group is not well-established, but according to Baldock (1982), it may be Palaeocene.



3. ECONOMIC GEOLOGY

Nineteen stream sediment samples and four heavy mineral samples were collected from the Plan de Milagro-Gualaceo section, which have been sent for analysis at the INEMIN laboratories.

Based on observations made in the field, the following materials were noted:

3.1 Graphite

This mineral is common in the black phyllites, but it is likely too fine-grained to be of any commercial interest. A graphite sample has been delivered to the German Mission for their comments.

3.2 Kaolin

The eastern belt of felsic volcanics is quite altered and associated with zones of potential kaolin. The clay mineral is white and plastic, and a sample has also been sent to the German Mission for identification.

3.3 Quartz veins

These are common throughout the Cordillera and can be found associated with gold mineralization. It should be noted, however, that no gold was found during panning.

3.4 Pyrite

Disseminated pyrite is common in the volcanic rocks of the Paute Group and also in the unnamed tonalitic intrusion, recently discovered west of Zapote.

3.5 Gold

Small amounts of gold were panned in the alluvium of the San Francisco River, upstream from Palmas. The origin of this gold is unknown.

4. COMMENTS ON NAMBIJA AND GUAYSIMI

Within the commission, a regional geological study was conducted in the Nambija and Guaysimi areas with the purpose of carrying out a reconnaissance and cooperating further technically regarding scientific research. Certain samples taken during this crossing were sent to England for microprobe analysis by the BGS (Dr. Tom Shepherd), who will send the results of the analyses, primarily for gold, at a later date; additionally, a general study of silver, sulphide content, etc., will be conducted to better clarify the origin of the deposit.

Geologically, the Nambija and Guaysimi areas are similar, consisting of contact rocks between hornblende granodiorite and granitic intrusives and sedimentary rocks of calcareous (limestone) composition. In Nambija, effusive rocks of intermediate and porphyritic composition with garnet and pyrite phenocrysts were observed.

Structurally, it was possible to determine by visual approximation that the highest concentration of minerals (gold, sulphides) in Nambija has a N-S strike with dips of 30 to 35 degrees toward the east.

In Guaysimi, it was difficult to observe orientations that could help structurally correlate with the Nambija area, given the few mining works carried out to date; however, a significant increase in minerals (sulphides) was observed.

Subsequently, the previously detailed structural geological study from Plan de Milagro-Gualaceo was carried out.

Ing. Francisco Viteri

Dr. John Aspden

CORDILLERA REAL PROJECT



No. 1508

QUITO, APRIL 06, 1987

TO : GERENTE TÉCNICO

FROM : ING. FRANCISCO VITERI and DR. JOHN ASPDEN
CORDILLERA REAL PROJECT

SUBJECT : Technical Report of the commission carried out from February 16 to 27, 1987, to the Provinces of Cañar and Azuay, Sigsig Canton, and Chigüinda Parish

SUMMARY:

The work carried out during this commission was conducted in Saraguro, as well as from Sigsig to Chigüinda, and from Sigsig-Mina Peggy to very near the hamlet called Infiernillos; all these sections are within the metamorphic belt of the Cordillera Real.

The geological study was carried out along improved roads and on foot traverses; together with the compilation of field geological-structural data, geochemical sampling was performed in the main streams of the studied areas.

Sigsig and Chigüinda formed part of the study axis of this commission, located in the moderately high and low parts of the mountain range, respectively, while in the central sectors, it cuts through the highest parts of the cordillera, reaching nearly 4000 meters above sea level (mamsl) in some cases. Both climate and vegetation are variable, depending on the altitude.

Within the geological context of the investigation area, recent volcanic rocks are exposed, likely corresponding to the Tarqui Formation, along with small dikes, intrusive plutons, and primarily metamorphic rocks. The Metamorphic Complex is represented by metavolcanic rocks and greenstones corresponding to the Paute Group; subsequently, we encountered a schistose sequence and, finally, further south, a semipelitic sequence represented by quartzites, phyllites, and quartz-phyllites.

Regarding Economic Geology, there is very little interest given that the area is not yet well known and, even more so, little studied. In any case, laboratory analysis results are awaited to gain an idea of the potential mineral indicators that may exist in the area.

1. INTRODUCTION

1.1 Objectives

This geological report is part of the compilation of basic field information, both geological and structural, scheduled for the current year within the Cordillera Real Project, in conjunction with Technical Assistance from the Government of Great Britain. This commission is the first of 1987, corresponding to the Southern Brigade.

The primary objective of the Geological Research program of the metamorphic belt of the Cordillera Real is the determination of the regional geology, structures, and mineralization associated with the Metamorphic Complex.

With the results obtained from the analysis of fluvial sediments, heavy minerals, and rocks, it will be possible to better correlate the geological findings. This work is being carried out within the provinces of Loja and Morona Santiago.

1.2. Assigned personnel

This commission was composed of:

Dr. John Aspden	Misión Británica
Ing. Francisco Viteri	INEMIN
Sr. Kerley Jurado	Driver/INEMIN

The mission took place from February 16 to 27 of the current year (1987).

1.3 Geographical and human characteristics

The study area is located approximately in the southern part of the country, in Sigsig Canton and Chigüinda Parish, corresponding to the provinces of Azuay and Morona Santiago respectively, within the following geographic coordinates:

Longitude	:	78° 45'	y	78° 55'	W
Latitude	:	03° 00'	y	03° 10'	S

Topographically, it corresponds to the southern Andean mountain system, featuring rugged relief in the central part of the section. It is possible to observe, within the study axis, the change in watercourse direction or the boundary of a hydrographic sub-basin.

Altitudes are variable, ranging from 1700 meters above sea level (mamsl) in the town of Chigüinda to 3800 mamsl at the ridge of the Cordillera.

The drainage is represented by two types of currents: those flowing toward the southeast, namely toward the Zamora River, which eventually discharges into the Atlantic as the Amazon, and others flowing in a NE direction toward the Paute River, which ultimately joins the Zamora. The main drainages in the research area are the Sangurima River, flowing southeast, and the Santa Bárbara River, which flows northwest before turning east to discharge into the Paute.

Access from Cuenca to Sigsig is via a paved road, followed by a third-order road heading toward Chigüinda, the latter being passable only during the summer. Another drivable road runs from Sigsig to the Peggy Mine, though it only reaches as far as the Reote River. Finally, there is a road under construction from Sigsig to the town of Principal.

2. GEOLOGY

2.1 Introduction

Originally, the plan was to complete the geotraverse between Saraguro-28 de Mayo-Cumbaratza during this commission. However, due to adverse weather conditions, this was not possible; instead, the geology exposed along the Sigsig-Chigüinda road was studied.

2.2 Base maps

The Sigsig-Chigüinda traverse is located within the Sigsig Sheet at a 1:100000 scale, which consists of the following quadrangles at a 1:50000 scale.

Sigsig	Principal
Gima	Chigüinda

Both the Principal and Gima bases are “census” planimetric maps with little control; there is no base map or aerial photography for most of the Chigüinda quadrangle. In contrast, the 1:50000 Sigsig base is topographically controlled, and this area also contains numerous access routes.

2.3 Previous works

Geologically, this area is poorly known, but currently, INEMIN is conducting mapping at a 1:100000 scale. Given the previously mentioned difficulties, however, it is unlikely that enough information will be obtained to guarantee the publication of the entire Sigsig Sheet 1:100000 in a standard format.

The 1:50000 Sigsig quadrangle contains two areas of known mineralization: near San Bartolomé to the NW and, approximately 7 km south of Sigsig along the Santa Bárbara River, the Peggy Mine. General information regarding these two areas is available in the INEMIN archives.

3. LOCAL GEOLOGY

Three main lithostratigraphic divisions have been recognized; from east to west, these are: the “Paute Group”, a central complex schist belt, and an eastern semipelitic unit, which together comprise the entirety of the Cordillera. The arrangement of these divisions is shown in Figure 1; it should also be noted that lithostratigraphic units similar to these were found in the northern portion of the Limón-Gualaceo traverse (see also Figure 1).

As has occurred in previous geotraverses carried out by the Cordillera Real Project, only the details of the pre-Tertiary “metamorphic” geology have been considered. However, it must be taken into account that large areas, particularly to the west, are covered by volcanic deposits of the Tarqui Formation. At the time of writing this report, thin sections are not available; therefore, the nomenclature of the various rock types is based solely on macroscopic identification.

3.1 Paute Group

For further details on the Paute Group, the reader should refer to Bristow et al. (1980). In general terms, the Paute Group consists of a predominant metavolcanic unit, which may also contain subordinate amounts of psammitic and impure pelitic materials, and a predominant metasedimentary unit consisting mostly of black, often graphitic phyllites, generally impure quartzite, occasional black metalimestone, and felsic phyllites (tuffaceous?).

South of Sigsig, the Paute Group is strongly tectonized and partially mylonitized, but consists mostly of still-recognizable metavolcanics or “greenstones”. These rocks are altered, generally showing a weak reaction to diluted HCl, and are dark to dirty green in colour. Generally, they do not contain quartzite and include small packages of psammitic and impure pelitic material.



Excellent exposures of foliated/banded mylonites occur immediately south of Sigsig on the eastern bank of the Santa Bárbara River, along the road leading to the Peggy Mine. The presence of these rocks and the general increase in tectonism of the Paute Group toward the east and toward the “central schist belt” suggests that these two divisions are separated by a major tectonic line. Structural readings obtained in this area indicate that this contact has a moderate to steep eastern dip (approximately 60° to 80°) and a NW strike. These structures are currently taken to represent the S₁ deformation; however, subsequent field checks should be carried out to establish this.

Rocks of the Paute Group, which also consist mostly of metavolcanics, are exposed north of Sigsig on the road to Chordeleg and north of the town of Principal. These outcrops have not been examined in detail, but they are visibly less deformed than those south of Sigsig.

Near Crio Dacte, highly altered schistose phyllites were observed, which exhibit a strong S₂ penetrative cleavage. These have been tentatively assigned to the Paute Group, but further work is necessary for confirmation.

3.2 Schist belt

The central schist belt is a complex unit consisting of a variety of lithologies but is characterized by the presence of pale green quartz-feldspathic, muscovitic, and chloritic schists. Phyllites are also present, which may contain minor amounts of graphite in the vicinity of the Peggy Mine; these are strongly silicified. Darker, more massive “metavolcanic” horizons of a dirty green colour were seen, and these appear macroscopically similar to the greenstones of the Paute Group.

In addition to the aforementioned rock types exposed at the main Peggy Mine, there is a massive biotitic granitoid with blue quartz, which contains a characteristic form with distinctive grey K-feldspar phenocrysts up to 3-4 cm long. Apart from the more massive “granitoid” outcrop, schists and gneisses are also found, and these appear to represent the tectonized outer margins of the blue quartz granitoid.

Despite being volumetrically small, the rocks containing blue quartz, and particularly the more massive granitoids, have been recognized elsewhere in the Cordillera Real (see previous Cordillera Real Project reports) and are of probable regional significance.

Structural readings obtained from the central schist belt are consistent with those of the Paute Group (NW-SE strikes and moderate to steep eastern dips); however, the general lack of bedding and primary textures suggests that these rocks have an older and more complex structural history. As stated previously, the northern contact of this belt with the Paute Group is considered tectonic, while the nature of the eastern contact with the semipelitic belt is unknown.

3.3 Semipelitic unit

Rocks belonging to this unit are well-exposed along the road to Chigüinda. Lithologically, they consist of a monotonous sequence of hard, greyish-blue impure quartzites, quartzose phyllites, and black, often graphitic phyllites. The rocks are generally weakly metamorphosed, although biotite is occasionally present. Quartz veins are quite common throughout, as is pyrite.

Structurally, the sequence has been affected by two main phases of deformation. A strong penetrative cleavage is common, related to gently plunging F2 folds with a cordillera-parallel strike. The intensity of the S2 cleavage, which has weak to moderate dips, increases toward the west and toward the assumed tectonic contact with the schist belt.

3.4 Intrusive rocks

Within the semipelitic belt, minor outcrops and heavily altered hornblende-biotite tonalite float blocks (monzonite?) were recorded along the road in the San Miguel area.

Fresh, loose intrusive clasts, consisting of undeformed hornblende-biotite tonalite, are present in the unnamed tributary of the Sangurima River on the left bank, approximately 2.9 km west of Chigüinda.

A small intrusive breccia, likely from the Tarqui Formation, and a small silicified quartz porphyry stock were observed in an area north and south of the Quebrada Reote in the central schist belt near the Peggy Mine.

Fluvial sediments and strongly mineralized concentrates collected from the area have yet to be analyzed; however, the fairly extensive occurrence of mineralization in the vicinity of the Peggy Mine is of obvious interest. Several studies and estimations have been conducted at the Peggy Mine, the most recent of which was by L. P. Entwistle (1982); copies of this report can be obtained from the INEMIN archives.

According to Entwistle (1982), the main minerals of economic importance are silver, copper, lead, and zinc. Minor amounts of iron have been obtained from panned concentrates. Regionally, this mineralization is spatially associated with a major tectonic line; in view of this, a geochemical sampling program should be carried out north and south of this area, along the projected continuation of this zone.

Whole-rock samples from this belt, which is strongly silicified in the vicinity of the Peggy Mine, should also be analyzed for gold. In this context, it is worth noting that one of the first rivers worked by Spanish conquistadors in search of alluvial gold was the Santa Bárbara River, between Sigsig and Gualaceo.



As previously stated, in the area of the Quebrada Reote, there is a strongly silicified quartz porphyry and an intrusive breccia, both likely related to the Tarqui Formation. These intrusions and their surrounding areas should also be sampled and analyzed for gold.

4. RECOMMENDATIONS

- (1) More detailed geochemical work should be carried out in the central schist belt, along the boundaries described above.
- (2) Attempts should be made to date (geochronology) the blue quartz granitoid at the Peggy Mine.
- (3) During the “dry” season, a detailed geological study of the central schist belt should be conducted along the Santa Bárbara River. The nature of the eastern contact between this belt and the semipelitic unit should also be studied.
- (4) Given the geological interest and economic potential of the area, the publication of the Sigsig Sheet at a 1:50000 scale could be considered.

5. REFERENCES

BRISTOW et al. (1980) Azogues, Hoja 73 (escala 1:100000) Mapa Geológico del Ecuador.

ENTWISTLE L. P. (1982) Report on the Mining Concessions held by Minera Austral S.A. in the Sigsig area, Azuay Province Ecuador. INEMIN, archive project No. 12238-Ecuador.

Ing. Francisco Viteri

Dr. John Aspden

CORDILLERA REAL PROJECT

ATTACH. Geological map

No. 3395

QUITO, AUGUST 04, 1986

TO : GERENTE TÉCNICO

FROM : ING. FRANCISCO VITERI and DR. JOHN ASPDEN
CORDILLERA REAL PROJECT

SUBJECT : Technical Report of the service commission carried out at sections 11 (Catamayo, Loja, Zamora) and 12 (Saraguro, Loja) completed from June 25 to July 11, 1986

SUMMARY:

This report corresponds to the start of the geological-structural and geochemical study in the metamorphic belt of the Cordillera Real in the south of the country. During this commission, sections 11 (Catamayo, Loja, Zamora) and part of 12 (Saraguro, Loja), Map No. 1, were completed.

The geological fieldwork was conducted along the highway and through small traverses. Simultaneously, geochemical sampling of fluvial sediments and heavy minerals was carried out in the drainages of primary importance.

The Saraguro and Loja areas are located in the Sierra austral, where the terrain is mountainous with altitudes varying between 1000 and 3800 meters above sea level (mamsl). The main river is the Zamora, whose drainage flows east toward the Atlantic Ocean.

In the Catamayo Valley, a warm and dry climate predominates; in contrast, the Zamora region is warm and humid.

The road network is passable throughout the year for the Saraguro-Loja, Catamayo-Loja, and Loja-Zamora routes.

The geology is represented by metamorphic and intrusive rocks.

The metamorphic rocks correspond to the Zamora Series and consist of: phyllites, slates, graphitic schists, quartzitic schists, and quartzites. This complex is intruded by granitic and granodioritic rocks, and occasionally tonalitic rocks, which primarily belong to the San Lucas Pluton. Regarding economic geology, few indicators of useful minerals have been found.



1. INTRODUCTION

1.1 Objective

The Geological Research study in the metamorphic belt of the Cordillera Real, carried out with Technical Assistance from the British Government, aims to determine the nature, interrelationships, genesis, and associated mineralization of the metamorphic rocks.

Within the current commission, a detailed study was conducted on sections 11 and part of 12, together with sampling of fluvial sediments, heavy minerals, and rocks, some of which will undergo radiometric dating. Additionally, a large portion of the already published Geological Sheets has been covered, such as those for Saraguro, Loja, Gonzanamá, and the Zamora quadrangle (a geological sheet without prior information); all these sheets are at a 1:100000 scale.

1.2. Assigned personnel

The commission was composed of:

Ing. Francisco Viteri	INEMIN
Dr. John Aspden	ODA
Sr. César Vinuesa	Driver/INEMIN

The mission took place from June 25 to July 11 of the current year.

1.3 Geographical and human characteristics

The study area is located in southern Ecuador, near the border with Peru. It is situated approximately between the following geographic coordinates.

Longitude	:	78° 55'	y	79° 20'	W
Latitude	:	03° 30'	y	04° 10'	S

The characteristic relief is Andean, with its respective inter-Andean basins; the terrain is mountainous with altitudes varying between 1000 and 3800 meters above sea level (mamsl).

Regarding climatology and vegetation, we can indicate that all altitudinal zones exist, from humid tropical to cold Andean; consequently, due to the variety of climate zones and relief, the vegetation is diverse.

Land cover is characterized by partial human intervention on the Andean foothills, with greater intervention in the inter-Andean zones.

From a hydrographic perspective, the Zamora River is the main river and constitutes an important tributary of the Amazon River, which discharges into the Atlantic. The Catamayo and Guayabal rivers drain toward the Chira River, which discharges into the Pacific Ocean.

The socioeconomic activity of the region is based on agricultural production, combined with artisanal and industrial activities in the inter-Andean zone. There is an incipient mining activity dedicated to the extraction of ceramic and construction materials.

The main roadway is the paved road that runs from Saraguro to Loja; Loja-Catamayo and Loja-Zamora.

1.4 Previous works

- Geología del Ecuador by Walter Sauer (1965)
- Geological map of the Loja province 1:250000 by Kennerley (1973)
- Geological Sheet of Saraguro (55; 1973) and Gonzanamá (57; 1975) by Kennerley
- Geological Map of Ecuador by Baldock (1982)

1.11 Work methodology

- Compilation of existing geological information
- Field verification, road survey
- Sampling of rocks, fluvial sediments, and heavy minerals; during this commission, 61 rock samples, 19 fluvial sediment samples, and 6 heavy mineral samples were taken
- Preparation of two outcrop maps and two rock and sediment sampling maps

1.11 Geomorphology

Two large typical landscapes are found: the Sierra and the Amazon region, described as follows:

The Sierra comprises the Cordillera Real (or Central), which is the highest and most irregular. It has a Palaeozoic core of metamorphic rocks whose grade decreases toward the west, covered in sectors by recent volcanic rocks on the summits and foothills, interrupted by the presence of plutons preferentially located in fault zones.

The Amazon region begins at the eastern foothills of the Cordillera, forming a large sub-Andean valley mostly covered by Quaternary deposits.



2. LITHOLOGY

2.1 Saraguro-Loja section

The main road between Saraguro and Loja runs in an approximately N-S direction and provides us with a cross-section of the contact between the intrusive and the Zamora Series (Kennerley, 1975). In the central part of the road, an interfingering contact between the metamorphic complex and the San Lucas pluton was observed. The Zamora Series essentially consists of phyllites to the north of the complex, while to the south, it is composed almost entirely of gneisses.

2.1.1 Phyllite unit

To the north of the San Lucas pluton, the Zamora Series is composed of a sequence of phyllites, graphite-rich phyllites, and minor schists, which are found unconformably overlain by the felsic volcanics of the Tarqui Formation (Kennerley, 1975).

Macroscopically, it can be observed that the phyllites consist mainly of quartz, graphite, and chlorite; small amounts of muscovite and chloritoid are also present (see Trouw, 1976). Pyrite is quite common, as are quartz veins and segregations. Patches of chistolite were noted in some outcrops; these are attributed to the presence of the San Lucas pluton at depth. Structural data obtained from the phyllites are variable, but in general, the main cleavage (S1) has a N-S direction and dips to the west at angles of approximately 65°. In most outcrops, a second crenulation cleavage appears; it is quite weak, generally non-penetrative, and appears to be related to tight folds with N-S directions that are steeply dipping or vertical.

2.1.2 Gneissic unit

At the southern end of the San Lucas pluton, between Las Juntas and Solamar (heading toward Loja), a sequence of quartz-feldspar-biotite gneiss, quartzites, and quartz schists is exposed. This sequence is clearly intruded by the San Lucas pluton and, in some places, contains small veins or segregations consisting of quartz, feldspar, muscovite, and tourmaline. Doleritic/andesitic dikes of variable orientation are very common, especially near the contact with the San Lucas pluton.

The structure of these rocks shows at least two phases of deformation. The main schistosity (S2?) has a N-NNE direction and dips steeply to the east. Tight to isoclinal F2 folds, with N-S to NE-SW directions and varying plunges, are quite common. In view of its higher metamorphic grade and its apparently complex structural history, it is possible that this gneissic belt represents either a lower portion of the Zamora Series or possibly a previously unidentified basement complex.

2.1.3 San Lucas pluton

This pluton was originally mapped by Kennerley and Almeida (1975) and takes its name from the small village of San Lucas located about 15 km south of Saraguro. The pluton is exposed over an area of approximately 150 km² and varies in composition from granitic to dioritic. The most common intrusive composition is likely granodiorite/tonalite, in which biotite represents the primary mafic phenocryst.

The tonalites are rich in biotite and are exposed in the vicinity of Vinuyacu Chico. In its more basic variant, hornblende becomes extremely important. The occurrence of hornblende within dioritic blocks suggests that part of the hornblende may be of another origin and occurs in the form of xenoliths.

According to Kennerley (1973), diorite commonly occurs around the margins of plutons and probably represents an early intrusive phase. This observation is based on the fact that hornblende-rich diorites occur as xenoliths within tonalite blocks found in the Quebrada El Gallo, located about 2 km north of Pucala toward the southern end of the Pluton (see geological map).

The contact at the north of the San Lucas Pluton with the Zamora Series was not observed; however, the presence of chistolite patches in the phyllites south of Saraguro possibly indicates the presence of that contact at depth. The southern contact is exposed in several places along and very close to the main road, and in the Quebrada Lirio (approx. 2 km south of Las Juntas), the pluton contains biotite gneiss xenoliths.

Aplitic and andesite/dolerite dikes of variable strike are relatively common both within the intrusion and in the surrounding areas of the Zamora Series.

The following K-Ar age determinations: 52 ± 2 Ma (biotite), 60 ± 1 Ma (plagioclase), 61 ± 1 Ma (biotite), 65 ± 2 Ma (biotite), and 68 ± 2 Ma (plagioclase) (reported by Hall and Calle, 1982), indicate a minimum intrusive age for the San Lucas pluton. In the Zenen River (Las Juntas), the presence of foliated tonalites may indicate more recent events.

2.2 Catamayo-Loja-Zamora section

The main road between Catamayo (La Toma) and Zamora crosses the Cordillera Real from west to east and, as such, provides an important cross-section through the Zamora Series. In this area, the rocks of the Zamora Series can be divided into two main units. The dominant one, which consists of a low-grade semipelitic sequence composed of quartzites, phyllites, and slates, is exposed between Catamayo in the west and Sabanilla in the east. To the east of Sabanilla, and likely associated with the contact zone of an unnamed gneissic pluton, there is an apparent increase in metamorphic grade, with biotite gneisses representing the most common rock type.



2.2.1 Semipelitic unit

2.2.1a Catamayo-Loja

The eastern and western limits of the metamorphic belt are in fault contact with the non-metamorphosed sediments of the Trigal Formation (Miocene) and the Gonzanamá Formation of the Palaeocene, respectively.

This sequence consists of interstratified quartzites with phyllites, graphitic phyllites, and minor quartz-feldspathic schists. Some phyllites are rich in chloritoid; smaller amounts of chlorite and muscovite are also present. Feldspar porphyry and dolerite dikes of variable orientation are exposed in the western part of the section.

Structural data are variable; their strike varies from NW-SE to NE-SW, and dips generally tend to increase toward the east. Original sedimentary features are frequently visible, and when measured, they are approximately coincident with S1. A weak and non-penetrative crenulation (S2), which is associated with fairly tight folds generally oriented in a N-S direction (F2) and of variable plunge, is generally visible in the more pelitic horizon.

2.2.1a-i The Gavilanes pluton

The new road between Catamayo and Loja cuts through the upper margin of a biotite pluton (previously unmapped) of the tonalite/granodiorite type. The extent of the intrusion, which is highly altered, is unknown, but it could represent the southern continuation of the San Lucas pluton described previously. This intrusive contains large xenoliths, some of which are partially digested, belonging to the Zamora Group.

2.2.1b Loja-Sabanilla

Between Loja and Sabanilla, the Zamora Series is composed of an interstratified semipelitic sequence of low-grade metamorphic rocks consisting of quartzites, graphitic phyllites, phyllites, and slates. In the west, these rocks are found unconformably overlain by the non-metamorphosed Miocene/Palaeocene Quillollaco Formation, while to the east, the rocks transition abruptly to gneissic and schistose rocks immediately east of Sabanilla.

Structurally, these rocks have often been affected by a main folding phase; when seen, these folds are quite tight, and upward-facing structures with NE strikes and amplitudes of a few hundred meters can be observed.

Structural readings across the sequence are fairly consistent, but there appears to be a slight change from strikes generally trending NE in the west to strikes trending N in the east. There is also an increase in dip from moderately high to almost vertical in the same direction.

Apart from S1 and the often weakly developed, nearly horizontal crenulation S2, associated with a N-NE trend, gently inclined and horizontal folds are also present.

Despite the fact that the Loja-Sabanilla sequence is separated from the one exposed along the Catamayo-Loja road by non-metamorphosed sediments belonging to the Loja basin, these two sequences are considered to belong to the same lithostratigraphic unit. In both sections, the ratio of psammitic to pelitic material, though variable from one site to another, is approximately 1:1. Both sequences are lithologically identical and consist essentially of low-grade metamorphic rocks which have undergone only one main phase of deformation.

2.2.2 Gneissic unit

In an area approximately 1 km east of Sabanilla and Zamora, the metamorphic rocks of the Zamora Series consist predominantly of biotite gneiss with subordinate quartzites and schists. According to Kennerley and Almeida (1975), a gneissic granite outcrops in this area, which they interpret as being of metasomatic origin. During the present investigation, large areas of “homogeneous” granite were not found; rather, a myriad of frequent irregular intrusive contacts of gneissic material and also of granodiorite-tonalite were encountered. At present, we interpret this area as one of stopping (remnants of an intrusive), which is likely associated with the contact, or possibly a roof zone, of a poorly exposed granitic pluton.

The apparent structural continuity of these rocks compared with those west of Sabanilla suggests that they probably belong to the Zamora Series. Certainly, the gneisses seem to be intimately related to the intrusive, but in the absence of more detailed work, we cannot rule out the possibility that this belt is part of an older, higher-grade basement complex.

Following the findings of Trouw (1976), apart to biotite and minor amounts of muscovite, these rocks locally contain sillimanite, cordierite, andalusite, tourmaline, and to a lesser extent, garnet. In the locations where we have observed these minerals, they are clearly related to intrusive contacts; thus, any interpretation regarding their regional significance must await a more detailed study (cf. Trouw, 1976).

The age of the Zamora Series is uncertain, but based on lithostratigraphic correlations, these rocks are believed to be equivalents of the Excelsior Group of Peru (Baldock, 1982), which are found unconformably overlain by fossiliferous Ordovician strata (Megard et al., 1971). Thus, it is generally accepted that the Zamora Series has a Lower Palaeozoic age.

The single K-Ar (biotite) dating of 52 ± 2 Ma, obtained from the biotite gneiss exposed east of Sabanilla, is considered to be a reset age or an “age of replacement” (Kennerley, 1975).



3. ECONOMIC GEOLOGY

Routine stream sediment geochemical samples and pan concentrates were collected during the present investigation; however, heavy rain prevented sampling of a large part of the Loja-Zamora cross-section. No gold was found in the pan concentrates, nor were there signs of mineralization in the clasts.

Many of the phyllites of the Zamora Series are of the graphitic type, and those areas containing especially high concentrations of the mineral are marked on the geological maps accompanying this report.

Quartz veins and segregations are extremely common throughout the Zamora Series, but where these were examined, no visible signs of mineralization were found.

According to the Metallogenic Map of Ecuador (1985) (Torres, 1985), small quantities of the following metallic minerals have been reported throughout the area covered by the present investigation.

3.1 Gold

Small amounts of alluvial gold, which presumably were derived from the metamorphic rocks of the Zamora Series, occur in the Tertiary sediments of the Loja basin and also to the NE of Zamora.

3.2 Copper and lead

Cu/Pb minerals have been reported in the NW part of the San Lucas pluton, and minor amounts of Cu minerals (chalcopyrite?), probably associated with quartz veins, occur within the Zamora Series east of Catamayo.

3.3 Zinc

The Oligocene Loma Blanca Formation in the NW corner of the Loja basin has been reported to contain small amounts of Zn (sphalerite?).

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Ing. Francisco Viteri

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CORDILLERA REAL PROJECT

ATTACH. Geological-structural maps, cross-section location maps, and sample location maps.



No. 0131

QUITO, JANUARY 14, 1987

TO : GERENTE TÉCNICO

FROM : ING. FRANCISCO VITERI and DR. JOHN ASPDEN
CORDILLERA REAL PROJECT

SUBJECT : Technical Report of the commission carried out from November 14 to December 01, 1986, for cross-section No. 12, Loja-Zumba

SUMMARY:

The work carried out during this commission focused on cross-section No. 12, which was conducted from Loja to Zumba, within the metamorphic belt of the Cordillera Real.

The geological study was carried out via the roadway and on-foot traverses. Along with the compilation of field geological information, geochemical sampling was performed on the drainage of interest.

Zumba (which belongs to Zamora Chinchipe) and Loja form the study axis of this commission; these zones are located in the lower parts of that axis, while the central part cuts through the highest sectors of the Cordillera. Altitudes are variable, ranging from 800 mamsl to 3800 mamsl, and consequently, vegetation and temperature vary accordingly.

Within the geological context, the investigation area is represented by intrusive and metamorphic rocks, except in the Malacatos basin sector.

The Metamorphic Complex is represented by high-grade metamorphic rocks, such as semipelitic rocks (gneiss, amphibolites); pelitic rocks have also been observed in smaller proportions. In conclusion, within this cross-section, it has been possible to differentiate between paragneiss and orthogneiss type rocks.

The intrusive rocks are represented by granodiorites, tonalites, and dikes of complex and varied composition.

Regarding Economic Geology, the eastern sector of the investigation area is of importance, where there are mining areas dedicated to the exploitation of primary and alluvial gold.

1. INTRODUCTION

1.1 Objectives

This geological report, which encompasses Geotraverse No. 12 and focused its study from Loja to Zumba, forms part of one of the final commissions of 1986 under the British Government Technical Assistance program.

The basic objective of the geological research program in the metamorphic belt of the Cordillera Real is the determination of the regional and local geology, structure, and mineralization associated with this metamorphic complex. Simultaneously, geochemical sampling of stream sediments, heavy minerals, and rocks was carried out. The study area is located in southern Ecuador, mostly encompassing the bordering provinces of Loja and Zamora Chinchipe.

1.2. Assigned personnel

The commission was composed of:

Ing. Francisco Viteri	INEMIN
Dr. John Aspden	ODA
Sr. Kerley Jurado	Driver/INEMIN

The commission was carried out from November 14 to December 01, 1986.

1.3 Geographical and human characteristics

The province of Loja and the canton of Zumba (which belongs to the province of Zamora Chinchipe) are located in the south and southeast of Ecuador, respectively, on the border with Peru. The research sector is located at Latitude 4° 57' S and Longitude 79° W. Topographically, it corresponds to the southern Andean mountain system, exhibiting abrupt reliefs. Two small mountain ranges that are constituents of the great Andean Cordillera belt can be observed within the study axis: the Sabanilla range and the Paredones range.

Altitudes vary between 800 and 3800 mamsl (at Laguna Cox). Temperature and vegetation depend on the altitude; the characteristic tropical rainforest can be found in the lower parts, while in the highlands, there are *pajonales* (tussock grasslands) and small shrubs. The drainage is represented by two types of currents: those flowing toward the Pacific and others toward the Atlantic. The Sabanilla range serves as the continental water divide. The main drainages to the east are the Palanda and Mayo rivers, whose waters reach the Chinchipe River, a tributary of the Marañón River, which flows into the Atlantic Ocean under the name of the Amazon. To the west, the upper watershed of the Catamayo River drains as a tributary of the Chira River, which empties into the Pacific Ocean. Access from Loja to Zumba can currently be made by road, which is used in the summer as it is an unpaved road currently under construction over a distance of approximately 140 km from Yangana.



1.4 Previous works

- Geological sheets published at a 1:100000 scale by INEMIN (DGGM) with technical assistance from the British Government.
 - Gonzanamá 1975
 - Las Aradas 1979
 - Zumba 1979
 - Loja 1975
- Geology of Loja Province, Southern Ecuador, J. B. Kennerley (1973)

1.11 Work methodology

- Compilation of existing geological information.
- Field checks, road surveys, and on-foot traverses.
- Sampling of rocks, stream sediments, and heavy minerals: petrographic samples were taken at 55 points, stream sediments at 20 slopes, and in some cases, heavy minerals.
- Regarding office work: preparation of base maps for the study and, finally, geological maps of the area.

2. GEOLOGY

2.1 Introduction

Geological maps at a scale of 1:100000 have been published for Loja, Gonzanamá, Las Aradas, and Zumba. These are supplemented by a geological map produced by the IFP for the Loja-Zumba-La Chonta road titled “*Formaciones Sedimentarias de la Sierra Tectónica Andina en el Ecuador*” (Savoyat et al., 1970); appropriate data obtained from reliable sources have been incorporated for the present study.

The road between Yangana and Isimanchi was opened only two years ago; therefore, most of the geological information obtained in this sector is new. During the present commission, in locations where time and access permitted, several trans-cordillera geotraverses were carried out, the locations of which are shown on the attached map. It should be noted that the alignment of the Yangana-Isimanchi road is approximate, but in general, it is located a few “kilometres” east of the old bridle path that appears on the 1:50000 scale topographic map of the area. As in previous reports, only the oldest and intrusive rocks are described. The Tertiary sediments outcropping in the Loja, Malacatos, and Zumba basins were not studied.

As with the previous traverses carried out by the Cordillera Real Project, it must be taken into account that the following interpretation is preliminary and may be modified in the future. At the time of writing the report, thin sections were not available; therefore, the nomenclature of the various rock types is based solely on macroscopic identification.

The Cordillera Real appears to be mostly composed of rocks that could be assigned to one of two lithostratigraphic units: the first consists of a monotonous sequence of low-grade semipelitic rocks, while the other, a more complex group, consists predominantly of higher-grade gneisses and schists. It is not the purpose of the present study to carry out geological sheet mapping; however, in the places where we have observed the rocks in the field, they are mostly easily recognized, suggesting they occur as mappable units whose distinction will surely represent one of the fundamental divisions of the metamorphic basement in southern Ecuador. In addition to these metamorphic units, several younger intrusives are present.

2.2 Semipelitic unit

This unit consists of generally impure low-grade quartzites, metasilstone, phyllite ($\pm$ graphite), slate, and occasionally greywackes. These are considered to have been derived almost exclusively from a continental source and apparently contain little to no volcanic material.

Structurally, the semipelitic rocks have a strike parallel to the mountain range, and the slopes vary from moderate to steep. On occasion, "abnormal" structural data were recorded, mainly toward the borders of the Tertiary basins, and it is assumed that these are related to local boundary faults. In locations where S_0 (bedding) and S_1 outcrop, they are parallel to subparallel, and frequently S_1 is clearly visible only in the finer-grained units. A fine S_2 crenulation was observed in some phyllites.

Rocks belonging to this unit are exposed along the main road between Loja and Malacatos in places where, structurally, Tertiary sediments separate these two basins. In the southern sector of the Loja basin, there is a new road going to Podocarpus National Park, which provides us with an excellent section through part of this sequence. Further south, these rocks are well-exposed mainly west of Yangana along a narrow road leading to Quinara. East of Yangana, similar rocks outcrop in the western part of the recently constructed road to Toledo.

South of Yangana, the exposure of semipelitic rocks decreases, and there is a corresponding increase in the gneissic unit. West of Zumba, along the western margin of the Zumba Tertiary basin, a narrow belt of graphitic phyllite blocks with/without pyrite outcrops. Based on regional correlations (see Plan de Milagro-Gualaceo and Saraguro-Loja, La Toma-Zumba reports), these rocks are considered to belong to the semipelitic sequence.



To the east of Zumba, the situation becomes more complex. In the sector where the main road crosses the Isimanchi River, there are exposures of bluish slates/phyllites which can be clearly assigned to the semipelitic unit. However, to the east and west of the Isimanchi River along the road, a sequence of impure green phyllites and schists outcrops. The exposure is quite poor, but towards the west between the town of Isimanchi and Zumba, these rocks are frequently deformed and present a well-developed S2 penetrative cleavage, which is related to F2 compact vertical folds. This increase in deformation could be related to local movements along the margin of the Zumba Tertiary basin, and undoubtedly similar F2 folds have been found in the phyllitic sequence to the west (see previous paragraph).

In any case, the composition of the rocks must be confirmed by means of thin sections; their green colour suggests they could contain volcanic components, which as such are not common in semipelitic units. For the moment and provisionally, we will include them within this unit, but further work is needed to establish an exact relationship with the meta-slate/quartzose phyllite that outcrops at the Isimanchi River.

2.3 Gneissic/schistose unit

This is a complex unit, but it consists primarily of a medium-to-coarse-grained gneiss of variable texture (banded, streaked, or veined), generally rich in biotite $\pm$ muscovite. Subordinate amounts of quartz schists, quartzites, and biotite and/or muscovite schists are present. This unit also includes a grey tonalite (biotitic $\pm$ muscovite), which is more homogeneous, generally medium-to-fine-grained, and less foliated. Minor amounts of migmatitic rocks were observed, and these can be found associated with muscovite/tourmaline pegmatitic borders.

Due to the similarity in composition between the biotitic gneiss and the tonalite, it is often difficult in the field to differentiate between ortho- and paragneiss. However, a preliminary attempt has been made to separate these rocks on the attached map using the following criteria: presence of xenoliths, rock texture/composition/homogeneity, and the quantity and distribution of biotite. It must be emphasized that more detailed petrographic work will be required, which in some cases will involve whole-rock geochemistry, to confirm the exact boundaries of the ortho- and paragneiss.

In addition to the rock types described above, there are amphibolites, which are frequently rich in biotite and are relatively widespread within the biotitic gneiss. They are of limited extent where they outcrop and likely represent basic dikes; furthermore, irregular pegmatitic veins or zones consisting of quartz and feldspar and carrying thick blocks of muscovite and/or biotite (up to 4 cm wide) were observed, these being quite common.

Structurally, the main penetrative fabric of the paragneiss generally has a mountain-range strike (trend), and the dips are normally steep to vertical. Based on evidence obtained in the field, this fabric is at least S₂, with S₀ (bedding) and S₁ having been largely destroyed. Although less developed, the orthogneiss also contains a foliation and/or displays a mineral lineation that apparently corresponds to the S₂ of the paragneiss.

2.4 Regional considerations/correlations

The age of the metamorphic rocks is unknown, but based on correlations with Peru, the gneissic unit is probably of Precambrian age and the semipelitic unit is Palaeozoic (Lower?).

In Ecuador, the semipelitic unit is correlated with lithologically identical rocks that are exposed between Catamayo and Sabanilla, and between Plan del Milagro and Gualaceo to the north. Similarly, the gneissic/schistose unit can be compared with rocks that outcrop immediately north of Loja, and also to the east of Sabanilla. Details of these areas have been provided in previous reports.

2.5 Intrusive rocks

The Río Mayo batholith (Guevara et al., 1979) is exposed along the main road immediately south of Palanda and northeast of Isimanchi. It is a composite intrusion which varies in composition primarily from granodiorite to tonalite. It also includes a smaller amount of monzonite? and, in the north between Agua Dulce and Quebrada Suhi, a distinctive greyish tonalite is present. In the 1:100000 scale geological map of Zumba previously published (Guevara et al., 1979), these latter rocks were mapped as the Celica Formation. However, for the time being and despite their distinctive colour, we prefer to include them as a separate intrusive phase of the Río Mayo batholith. Along the batholith, dikes, sills, and apophyses of felsite and porphyry are quite frequent, and these likely represent the youngest phase of the intrusive. The age relationships between the other intrusive units were not established, but their approximate distribution is shown on the attached map.

The Río Mayo batholith is non-foliated and contains both biotite and hornblende in varying proportions. No age data are available, but they are presumed to be Cretaceous (Baldock, 1982).

Blocks of undeformed calc-alkaline granitoids were observed in several rivers. These are especially common west of Zumba in the Río Ahogado and in Quebrada Mono, and west of Palanda in the Río Blanco and the Río Jíbaro. The relationship of these rocks to the older gneisses is unknown, but their presence clearly indicates the existence of unmapped intrusions within the mountain range areas.

In the 1:100000 scale geological map of Zumba (Guevara et al., 1979) and Las Aradas (Kennerley et al., 1979) near Palanda, a hornblende tonalite known as "The Palanda Batholith" has been mapped. The aforementioned authors considered this body to have a metasomatic origin and therefore differentiated it from the Río Mayo Batholith to the south.



During the present study, observations between Palanda and Quebrada de las Toronjas to the North were limited; however, the dominant rock type found was a medium-to-coarse-grained paragneiss, generally rich in biotite. As previously stated, south of Palanda, a granodiorite/tonalite outcrops along the main road, containing varying amounts of both hornblende and biotite; as shown in the attached map, we have included this sector as part of the Río Mayo batholith. Emphasis is placed on the fact that this interpretation is preliminary, and more detailed work will be necessary later to confirm it. Future planned isotopic studies should prove whether these rocks are indeed metasomatic/continental, as the present study suggests, or are part of the igneous composition associated with calc-alkaline plutons derived from the surface.

3. ECONOMIC GEOLOGY

Stream sediment samples collected in this area must be analyzed; however, no signs of mineralization have been found in the river blocks.

3.1 Gold

Alluvial gold has been panned from the Isimanchi River near the town of Isimanchi, but its origin is unknown; the presence of gold has also been reported in the Palanda River and in the Huanamaca River north of Palanda. Neither of these last two occurrences was confirmed by the current study.

3.2 Tourmaline-Muscovite

Pegmatitic patches of tourmaline and muscovite occur in the metamorphic basement rocks. No non-metallic minerals were found associated with these rocks; however, panned concentrates will be analyzed for iron and tungsten as soon as facilities become available.

3.3 Garnet

Bright red garnet was panned in the Río Molino (Valladolid) and from the Quebrada de Rubis (La Diversión). No “in situ” rocks with garnet samples were found, but it is assumed that these are associated with contact metamorphism.

3.4 Non-metallics

Metamorphic rocks, as well as intrusive rocks, can be used as construction and ornamental material due to their hardness, the polychromy (variety of colours) of their tones, and their different structures.

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CORDILLERA REAL PROJECT

ATTACH. Geological-structural map, geochemical sampling maps.

